DOCUMENT RESUME

ED 445 953 SO 031 091

AUTHOR	Kuby, Michael
TITLE	Population Growth, Energy Use, and Pollution: Understanding the Driving Forces of Global Change. Hands-On! Developing Active Learning Modules on the Human Dimensions of Global Change.
INSTITUTION	Association of American Geographers, Washington, DC.
SPONS AGENCY	National Science Foundation, Arlington, VA.
ISBN	ISBN-0-89291-235-9
PUB DATE	1996-00-00
NOTE	281p.; Module developed for the AAG/CCG2 Project "Developing Active Learning Modules on the Human Dimensions of Global Change." For related items, see SO 031 087, SO 031 089-094, and SO 031 096.
CONTRACT	DUE-9354651
AVAILABLE FROM	Association of American Geographers, 1710 Sixteenth Street NW, Washington, DC 20009-3198; Tel: 202-234-1450; Fax: 202-234-2744; E-mail: gaia@aag.org; Web site: http://www.aag.org/.
PUB TYPE	Guides - Classroom - Teacher (052)
EDRS PRICE	MF01/PC12 Plus Postage.
DESCRIPTORS	*Critical Thinking; Demography; Ecology; Economics; *Energy; *Environment; *Global Approach; Higher Education; *Pollution; *Population Growth; Thinking Skills; Undergraduate Students; Undergraduate Study

ABSTRACT

Since the beginning of the scientific revolution in the 1700s, the absolute scale of the human economy has increased many times over, and, with it, the impact on the natural environment. This learning module's activities introduce the student to linkages among population growth, energy use, level of economic and technological development and their combined impacts on the environment. The module aims to actively engage students in problem solving, critical thinking, scientific inquiry, and cooperative learning. It is appropriate for use in any introductory or intermediate undergraduate course that focuses on human-environment relationships. Following a guide and a summary, the module is divided into the thematically coherent units: (1) "Human Driving Forces of Global Change Background Information"; (2) "Population Growth Background Information"; (3) "Energy Use Background Information"; and (4) "Total Pollution Output from the Human Economy into the Environment Background Information." Appendixes list teaching aids, textbooks, data sources, videos and computer support, selected Internet sites, references on related subject matter, and suggested readings. Contains 8 tables, 24 figures, a list of acronyms, a glossary, supporting materials, and 66 references. (BT)

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HANDS-ON!

Population Growth, Energy Use, and Pollution: Understanding the Driving Forces of Global Change

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An Active Learning Module on the Human Dimensions of Global Change

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HANDS-ON!

DEVELOPING ACTIVE
LEARNING MODULES ON THE
HUMAN DIMENSIONS OF GLOBAL CHANGE

Population Growth, Energy Use, and Pollution: Understanding the Driving Forces of Global Change

Module developed for the AAG/CCG2 Project
"Developing Active Learning Modules on the Human Dimensions of Global Change"

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Developing Active Learning Modules on the Human Dimensions of Global Change
"Population Growth, Energy Use, and Pollution: Understanding the Driving Forces of Global Change"

ISBN: 0-89291-235-9

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Project director, Susan Hanson, Clark University, acknowledges the support of the National Science Foundation (NSF) to the Association of American Geographers (AAG) (Grant No. DUE-9354651) for the development of these teaching materials. Administrative support is provided through the AAG's Second Commission on College Geography (CCG2) and the AAG's Educational Affairs Director, Osa Brand, and her staff. General project support is provided by Clark University, Worcester, Massachusetts which also hosted a workshop to develop the modules further. The hard work of the conference participants evident in these materials is greatly appreciated. Kay Hartnett, Clark University, gave most generous and proficient graphic design advice. Module authors, co-authors, and other contributors are solely responsible for the opinions, findings, and conclusions stated in this module which do not necessarily reflect the views of the NSF or AAG.

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Editor's Note

A major goal of this project, "Developing Active Learning Modules on the Human Dimensions of Global Change," is to disseminate instructional materials that actively engage students in problem solving, challenge them to think critically, invite students to participate in the process of scientific inquiry, and involve them in cooperative learning. The materials are appropriate for use in any introductory and intermediate undergraduate course that focuses on human-environment relationships.

We have designed this module so that instructors can adapt it to a wide range of student abilities and institutional settings. Because the module includes more student activities and more suggested readings than most instructors will have time to cover in their courses, instructors will need to select those readings and activities best suited to the local teaching conditions.

Many people in addition to the principle author have contributed to the development of this module. In addition to the project staff at Clark University, the participants in the 1995 summer workshop helped to make these materials accessible to students and faculty in a variety of settings. Their important contributions are recognized on the title page. This module is the result of a truly collaborative process, one that we hope will enable the widespread use of these materials in diverse undergraduate classrooms. We have already incorporated the feedback we have received from the instructors and students who have used this module, and we intend to continue revising and updating the materials.

I invite you to become part of this collaborative venture by sending your comments, reactions, and suggested revisions to us at Clark. To communicate with other instructors using hands-on modules, we invite you to join the Hands-on listserve we have established. We look forward to hearing from you and hope that you will enjoy using this module.

Susan Hanson
Project Director

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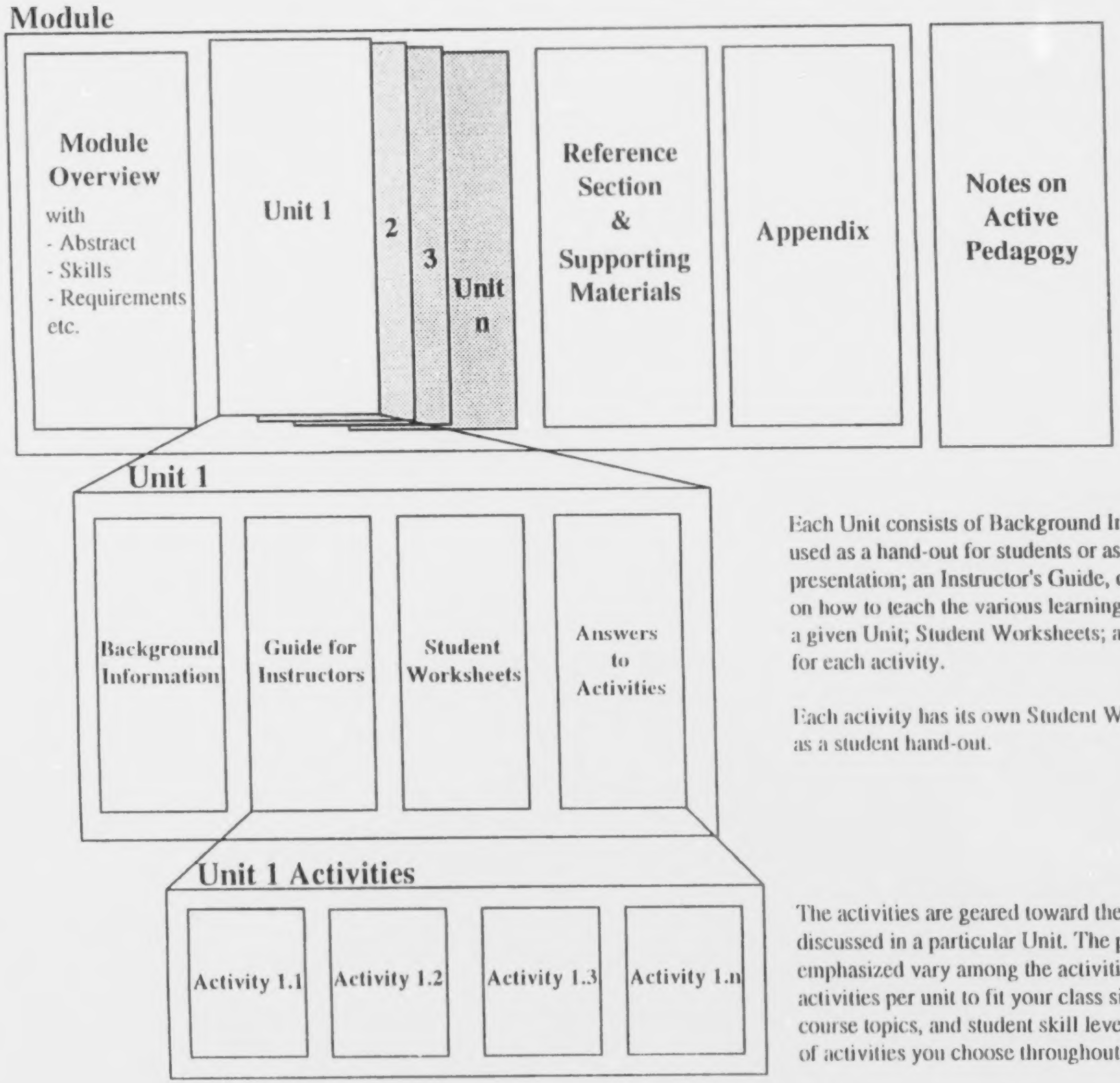
List of Acronyms

AAG	Association of American Geographers
BTU	British Thermal Units (energy unit)
CBR	Crude Birth Rate
CCG2	(AAG's) Second Commission on College Geography
CDR	Crude Death Rate
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon dioxide
DDT	Dichlorodiphenyltrichloroethane (insecticide)
DOE/EIA	(US) Department of Energy/Energy Information Agency
DSM	Demand side management
ESD	Energy Service Demand
FERC	(US) Federal Energy Regulatory Commission
GDP	Gross Domestic Product
GNP	Gross National Product
HDGC	Human dimensions of global change
IEA	International Energy Agency
IGU	International Geographical Union
LDCs	Less-developed countries
mtoe	million tons of oil equivalent (energy unit)
NASA	(US) National Aeronautics and Space Administration
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
PRB	(US) Population Reference Bureau
PEP	Primary Energy Production
SO_2	Sulphur dioxide
TFC	Total Final Consumption
TFR	Total Fertility Rate
toe	tons of oil equivalent (energy unit)
TPES	Total Primary Energy Supply
UK	United Kingdom
UN	United Nations
UNCPD	United Nations Conference on Population and Development (Cairo, 1994)
UNESCO	United Nations Educational, Scientific and Cultural Organization
US(A)	United States (of America)
US/DOE	United States Department of Energy
WDR	(World Bank's annual) World Development Report

Guide to this Module

This guide is meant to help you navigate this module.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The module is divided into Units, i.e., sections that are thematically coherent and that could, if necessary, stand alone. In addition, the module contains a Reference Section, Supporting Materials and an Appendix. The Supporting Materials can be used to facilitate the teaching of this module or simply to augment it with interesting ideas and information. Additional sections with further information may or may not be present, e.g., a list of accronyms, or a glossary. A separate section on Active Pedagogy comes with every module purchase.

Each Unit consists of Background Information that can be used as a hand-out for students or as the basis for an in-class presentation; an Instructor's Guide, consisting of suggestions on how to teach the various learning activities associated with a given Unit; Student Worksheets; and the Answers expected for each activity.

Each activity has its own Student Worksheet that can be used as a student hand-out.

The activities are geared toward the theme(s) and concepts discussed in a particular Unit. The particular skills and themes emphasized vary among the activities. Choose one or more activities per unit to fit your class size, time, resources, overall course topics, and student skill levels. Be sure to vary the types of activities you choose throughout the module.

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Summary: Population Growth, Energy Use, and Pollution: Understanding the Driving Forces of Global Change

Abstract

Since the beginning of the scientific revolution in the 1700s, the absolute scale of the human economy has increased many times over, and with it, the impact on the natural environment. The human population has grown exponentially and per capita resource consumption and waste production have skyrocketed along with the standard of living. The combined effect of population growth and increased resource use per person (energy will be used as an example here) is a multiplicative increase in the *material throughput* of the human economy from resource sources to waste sinks. The activities in this module introduce the student to linkages among population growth, energy use, level of economic and technological development and their combined impacts on the environment. Students will learn key concepts like exponential population growth, hidden momentum, technological and structural change, energy intensity, and elasticity. We also present various schools of thought about the relationship between population and environmental impacts, although the emphasis here is on the multiplicative/synergistic school. Throughout, the activities foster critical thinking and analytical skills, reading comprehension, and synthesis of the complex interrelations among the driving forces behind global change.

General Module Objectives

✔ To introduce the student to the absolute scale of population and energy use in today's world

✔ To tie these two driving forces of global change together via the concept of material throughput

✔ To provide the student with the key economic and demographic concepts needed to understand the geographic variability and internal dynamics of the growth of population and energy use

✔ To illustrate those key concepts via quantitative analysis of energy and population data

✔ To critically evaluate the relationship between population growth, affluence, and environmental degradation

Skills

This module enables students to

✔ understand and apply the theoretical models and concepts explaining population growth and energy use

✔ explain the differences between the energy and population development paths of various countries

✔ produce, interpret, and critically assess graphs with linear and logarithmic scales

✔ understand the correspondence between longitudinal and cross-sectional analysis

✔ apply algebraic math skills for calculating population growth, energy efficiency, etc.

✔ summarize and critically assess arguments and data and to synthesize information and theories

✔ engage with the local community

Activities

✔ Graphing and calculating population growth

✔ Examining the demographic transition theory

✔ Simulating the hidden momentum of population: a "what-if" scenario for Mexico
✔ Decoupling energy use from economic growth: is it possible?
✔ Putting it all together: how population, consumption, and technology interact with other forces to affect the environment.

Material Requirements

✔ Student Worksheets (provided)
✔ Graph paper (provided)
✔ Energy use data (provided)
✔ World Population Data Sheet or other source of current population data
✔ Thematic maps (of wealth, population, or energy use)
✔ Calculators
✔ Pencils
✔ Readings (some provided)

Human Dimensions of Global Change Concepts

✔ Human driving forces
✔ Population dynamics concepts (exponential growth, the demographic transition theory, population density, the hidden momentum of population)
✔ Schools of thought on the relationship between population and environment
✔ Systems concepts (throughput, delays, sources, sinks, feedbacks, and nonlinearities)
✔ Energy use concepts (energy intensity and elasticity, structural and technological change, renewable and nonrenewable resources, and demand side management)
✔ Global climate change
✔ Mitigation

Geography Concepts

✔ Human impacts on the environment
✔ Intercountry variation
✔ Scale
✔ Natural resources
✔ Population distribution
✔ Carrying capacity
✔ Development
✔ Diffusion

Time Requirements

In class 6-15 hrs, homework 5-40 hrs, required readings 3-12 hrs (depending on selection of in-class and at-home activities and reading assignments). In 2 weeks, the instructor could introduce the bare essentials of the material and do some of the shorter activities from each of the four units in the module. A minimum of 3 weeks is recommended to cover population and energy adequately. In 5 weeks, the instructor could cover all of the materials in depth and do many of the activities. If the instructor has less than 2 weeks available, he/she could choose a subset of topics to focus on (i.e., population growth, the demographic transition, or the schools of thought on how population growth effects the environment).

Difficulty

The population portion of this module is for the lower division undergraduate level. The energy portion might need extra adaptation to work well for freshmen and sophomores. Students will use some applied mathematics (percentages, exponents, scatter plots, curve-fitting by eye; logarithmic graphs). The module suggests quite a bit of reading, but it can be taught with lower reading intensity.

Module Overview

The scale at which human activity alters the natural environment has increased dramatically in the last three centuries. The Scientific Revolution that began in the 1700s was more than just an Industrial Revolution: it also transformed medicine, agriculture, settlement, and sanitation. Taken together these changes enabled people to live longer and wealthier lives. As a consequence total population and per capita resource use began to grow exponentially, though not at the same rate everywhere. Total material flow from the resource base, through the human economy and back into the environment as waste, has multiplied many times over and is threatening the environmental systems upon which life on Earth depends. Opinions among scientists, politicians, and citizens are deeply divided as to what the future holds.

This module introduces students to some of the fundamental questions about the connections among population, resource and energy use, and environmental impacts.

- What factors have caused the enormous growth of population and energy use in the past?
- To what extent is population growth responsible for the environmental problems we see today?
- What opportunities are there for slowing population growth, per capita energy use, or the environmental harm caused by each unit of energy use?

The module highlights the complexities, non-linearities, and delays that complicate the relationships among population, wealth, and environmental impacts. Unit 1 introduces the concept of human-induced global change and provides an overview of the different approaches to framing the population-environment relationship. The next two units focus on population and energy use, respectively, in the context of global change. The unit on population introduces basic population geography concepts and skills (demographic transition theory, exponential growth, etc.) and explores the relationship between population and energy use. The unit on energy focuses on supply vs. demand issues and trends in energy consumption. Unit 4 returns to the various ways that the relationship between population and environmental change has been framed and provides students an opportunity to synthesize the knowledge gained in previous units about the relationships among population growth, consumption and technology, and environmental degradation.

The module provides students with the concepts and tools needed to make sense of the often contradictory and contested information on population, energy, and environment and to provoke them to draw their own conclusions based on a comprehensive understanding of the linkages among demographic, economic, environmental, and resource systems. The activities are designed to develop students' (1) appreciation of the global linkages among population, energy usage, and environmental impacts; (2) understanding of the basic concepts and dynamics of population growth; (3) understanding of energy usage and links to economic activity and growth; and (4) assessment of the enormous and value-charged complexity of the population-environment relationship. Throughout, students are challenged to think critically and practically about their own habits and lifestyles.

1 Human Driving Forces of Global Change

Background Information

Introduction to Global Change

On December 12, 1996, 5.7 billion people inhabited the earth, over 200,000 more than the day before, and over 85 million more than on the same day in 1995. In one year, we consumed an amount of fossil fuels equivalent to the energy in 42 billion barrels of oil and released approximately 22 billion metric tons of carbon dioxide into the atmosphere (WRI 1996). As far back as 1873, the Italian geologist Stoppani suggested that the world had entered the "**anthropozoic era**,"[1] meaning, one in which the power and universality of humanity's influence on the natural world could be compared to the great geologic, energetic, and biotic forces of the earth. What would Stoppani say today, with four times as many people inhabiting the planet, most of whom are far richer and consume vastly more resources than the typical late 19th century Italian and who use technology that even Leonardo da Vinci could not have envisioned? He might predict that the anthropozoic era will be the shortest geologic era on record (and what a record it would leave behind!) as a direct result of humanity's effect on nature.

Clark (1988) identified four fundamentally different mechanisms by which humans affect the natural world:

1. taking needed materials and energy (resources) out of the natural subsystems (causing, e.g., soil nutrient loss), or redistributing them (*e.g.*, through water diversions);
2. releasing pollutants of all kinds into different natural subsystems;
3. transforming the physical surface of the earth in terms of its structure (e.g., terracing), its surface characteristics (e.g., its reflectance [albedo]), and its habitats (e.g., wetlands drainage); and
4. by removing or manipulating species from ecosystems through harvesting, hunting, introducing competitive species, or genetically altering species by domestication, hybridization, or gene-splicing.

In addition, there are interactions among the above four categories, such as species extinction caused by pollution or habitat destruction.

Clark further pinpointed agriculture, industry, and energy consumption as the three main groupings of human activities that precipitate these four fundamentally different kinds of environmental changes (though one might usefully separate out settlement, mining, or animal husbandry as distinct activities). To study the human causes of environmental change, we could adopt a piecemeal approach of looking at how each of the three kinds of human activities causes each of the four kinds of environmental change -- a 3x4 matrix of activities and impacts that even thus disaggregated is woefully oversimplified (see Figure 1). However, current scientific thinking about global change views all impacts as being caused by the fundamental process of *human-induced change in energy and material flows.* Obviously, any form of pollution (broadly understood) -- from global CO_2 emissions in the air, to radioactive waste in the ground, to dioxins in the waters -- can be seen in this light. But so too can soil erosion, strip mining, damming of rivers, deforestation, wetlands drainage, irrigation, hunting, and terracing. Whether purposefully or inadvertently, altered flows of energy and materials in nature also affect flows of food and industrial inputs into the human economy.

---

[1] Words that appear in bold can be found in the Glossary.

Figure 1: Matrix of Human Activities and Impacts on the Environment

Types of Impacts	**Main Groups of Human Activities**		
	Agriculture	*Industry*	*Energy Cons.*
Resource Use			
Pollution			**Focus of this module**
Struct. Change			
Species Removal			

Source: Constructed after Clark (1988)

This module focuses on the forces (population and energy use) driving the enormous global growth in energy-related atmospheric emissions. While this emphasis corresponds to only one of the twelve cells in the 3x4 matrix shown in Figure 1, the driving forces also underlie other activities and impacts. Population growth clearly increases the scale of agricultural and industrial activities, both in their spatial coverage of the earth's surface and in their intensity. Population growth also increases polluting and non-polluting impacts. Energy production and use directly contribute to all four kinds of environmental impacts, and they resemble industry (though less so agriculture) in their close relationship with economic growth. In short, this module will look at the interconnected driving forces of global environmental change, with particular emphasis on

(1) population and (2) energy. These driving forces are especially well-suited for linking the human economy with our environment and climate.

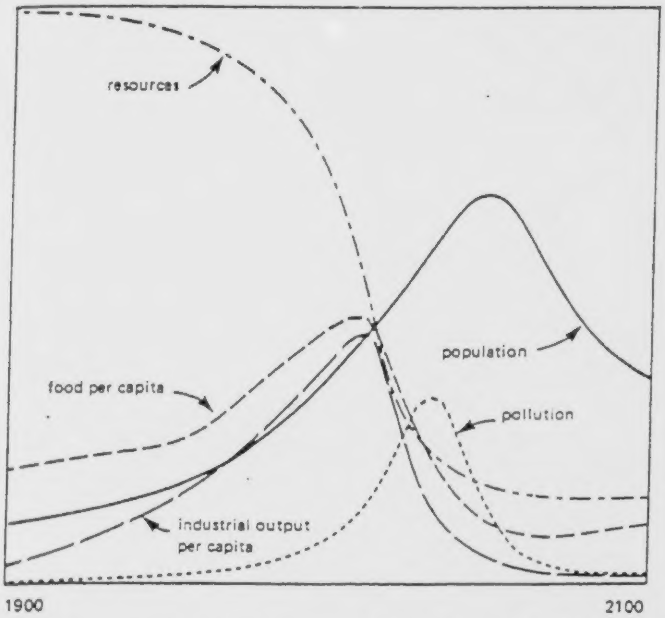
Introduction to the Global Perspective in Environmental Studies

People have been aware of the dangers of pollution and other environmental impacts since the early days of the Industrial Revolution. The smoke from England's factories, and the coughing it induced were, after all, hard to ignore. The effects of invisible pollution, however, were not taken seriously until Rachel Carson (1962) exposed the insidious dangers of DDT and other chemicals in *Silent Spring* and Japan's Minimata Disease (first identified in 1956) was linked to high mercury concentrations in fish. As environmental awareness spread, scientific activity increased and evidence of human impacts to the environment mounted. Still, in these early days, the problems were usually seen as localized events that may have been happening at sites around the world but were not necessarily part of any linked global system.

The idea that many environmental problems were globally interconnected came to the fore in the early 1970s (Buttel, Hawkins, and Power 1990). Much environmental science and activism merged around the concept of "limits to growth," the title of the best-selling book by Meadows and colleagues (1972) that sold 9 million copies. In *Limits to Growth* researchers applied the new science of systems dynamics to simulate the future of the global human-environment system. *Limits to Growth* argued that **exponential growth** of population and wealth lead to overshooting the **carrying capacity** of the earth. Carrying capacity is a quantity that is somewhat difficult to measure, but it is broadly defined as the number of people (or other species) an area can support indefinitely (i.e., sustainably) given the current technology (Higgins et al. 1982). Overshooting the carrying capacity of an area implies that the presence of too many individuals overstresses the food, air, and water resources upon which they depend for survival. Malthus, an eighteenth century minister and social thinker, suggested that this condition would lead to war, famine, or plague, thereby reducing the population to a level below the carrying capacity. Meadows and colleagues built a number of corrective paths into their model for bringing population, resource use, and environmental problems under control in less calamitous ways, but those mechanisms were outweighed by the sheer scale and inertia of the system. *Limits to Growth* is most famous for its lasting images of exponentially rising curves that overshoot the carrying capacity, turn down, and plummet, signifying a collapse of population, food supply, standard of living, and life expectancy.

For the majority of people who did not read the book, the defining image of this period of environmental thought may have been the photographs of planet Earth from the Apollo missions to the Moon, its continents surprisingly close together, its clouds and waters interconnected, spinning alone in the vacuum of space. This image of "Spaceship Earth" instilled in people's minds a sense of the finiteness of our earth. When the 1973-74 OPEC oil embargo set off the world's first oil crisis, the *Limits to Growth* graphs seemed to be prophetic. During the "alternative lifestyle" period of the 1960s and early 1970s, many students were intrigued by *Limits to Growth*'s message that part of the problem was our consumer lifestyle and our seemingly infinite appetite for material goods. Other similar studies, including the enormous *Global 2000 report* commissioned by President Carter (US Council on Environmental Quality and US Department of State 1980) followed and supported these conclusions and warnings.

Figure 2: Limits to Growth -- A Scenario of a Collapsing World



Source: Meadows *et al.* 1972. *Limits to growth*. New York: Universe Books, their Figure 35, p. 124. Reprinted with the permission of Universe Books.

The limits to growth **paradigm** came under fire, however, for a number of historical, scientific, and cultural reasons; as a result, environmentalism, which until then was largely based on this type of thinking, lost some of its unity and appeal. Scientifically, global modeling was attacked for what was perceived as built-in pessimistic biases, lack of regional differentiation, and inadequate consideration of market mechanisms and technological change (Cole et al. 1973). As new oil was discovered in Alaska and the North Sea, as the OPEC unity crumbled, and as automakers responded with more fuel-efficient cars, the running-out-of-oil scenario seemed like just another cry of "wolf" by anti-business environmental "shepherds." The simultaneous farm crisis in the US, during which the federal government paid farmers *not* to grow crops, made claims of a global food shortage sound contradictory. Stagflation (economic stagnation plus inflation) struck in the late 1970s, followed by deep recession in the early 1980s, making any suggestion of restraining economic growth a form of political suicide.

To people in the US and Western Europe, not to mention to those in the poverty-stricken Third World, the *Limits to Growth* recipe for the future was anathema. Vargish (1980) argued that the main reason for people's antipathy to the *Limits of Growth* paradigm was its suggestion that everything would *not* work out o.k. if left to the laws of God, Adam Smith, *or* Karl Marx.

According to Vargish, the *Limits* paradigm simply "strips us of the assurance offered by past forms of Providence and progress and ... thrusts into our reluctant hands the responsibility for the future. And that is why the person sitting next to you hates *Limits to Growth*" (Vargish 1980: 187).

Global change emerged in the mid- to late-1980s as a new unifying banner for the environmental movement and the environmental sciences. The defining issues for the global change movement are the "ozone hole," the destruction of tropical rainforests, and what is known as the **greenhouse effect**. Policy-makers and public opinion makers tend to favor technological, market-oriented, and international responses to these challenges.

The "**ozone hole**" and the scientific, journalistic, and political response to it is a model for the new global paradigm (Benedick 1991; Meadows et al. 1992). In just over a decade after the publication of the first papers suggesting that chlorofluorocarbons (**CFCs**) could thin the **stratospheric ozone layer** (Stolarski and Cicerone 1974; Molina and Rowland 1974), scientists of the British Antarctic Survey found proof (Farm, Gardiner, and Shanklin 1985). Eventually, the scientific evidence convinced 36 of the world's major countries to sign the Montreal Protocol in 1987 to freeze CFC production at 1986 levels, followed by 20% and 30% reductions by 1993 and 1998. Then, as the South Pole "ozone hole" widened and potential health effects became more widely known, and as corporations saw the profit opportunities in engineering substitute refrigerants, the world community surprised itself by forging agreement among 92 countries to phase out CFC production altogether by 2000.

Buttel, Hawkins, and Power (1990) suggested that today's global change movement shares some of the thinking of the *Limits to Growth* paradigm but differs in some significant ways. The commonalities between the old and new environmental paradigms are their global scope, their systems-thinking approach, and their neo-Malthusian preoccupation with the gross scale of human activity (see *The Role of Population in Environmental Change: A Survey of Perspectives* later in this Unit). Because of the complex systems involved, another commonality has been the use of sophisticated computer models. And, of course, "both [global] perspectives are characterized by a predicted pathological scenario of environmental collapse, which in turn is held to threaten the survival of the human species" (Buttel, Hawkins, and Power 1990: 59). For instance, tropical deforestation is a *regional* equatorial phenomenon that has captured the global imagination because of its role in the *global system* as a water purifier, carbon sink, and species reservoir, not to mention its importance as a home to indigenous peoples and as a tourist destination. Pictures from space complement studies done in the field, and the combination of approaches provides a more comprehensive understanding of tropical forests and how human activities are changing them. Like the "ozone hole" and the greenhouse effect, deforestation is linked to the exploding world population and wealth, though in complex and globally non-uniform ways.[2]

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[2] There is a growing recognition that deforestation is not just a tropical phenomenon, e.g. deforestation in Siberia.

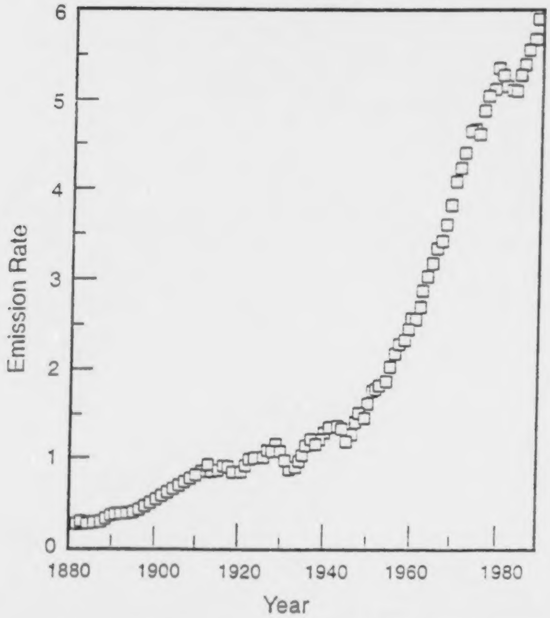
What marks the new global environmental paradigm as different from the last is that the private corporate sector and their technologies are seen as part of the solution rather than part of the problem. In the economically competitive 1990s, few dare suggest curtailing economic growth. The need for continued economic growth is the one thing upon which liberals and conservatives, ex-communists and capitalists, "First Worlders" and "Third Worlders" seem to agree. Other defining differences between the old and the new global environmental paradigms seem to be an emphasis on market mechanisms, partnership, and compromise as opposed to authoritarianism, antagonism, and extremism. These differences, along with the "dread factors" common to the *Limits to Growth* scenarios, seem to be responsible for the generally favorable reception (so far) given to global environmental change by journalists, politicians, business leaders, scientists, and the public (Buttel, Hawkins, and Power 1990).

Although there was scientific *and* political agreement on ozone, it is far less likely that there will be a scientific and political consensus to address the climate change (greenhouse) threat in a similarly swift and unified way. Achieving such a consensus will depend on many factors, including the degree of scientific consensus, the quality of the scientific evidence, the strength and nature of the associated hazards, the mitigation cost to the various parties within and between countries, and the availability and acceptability of technological solutions. Because fossil fuels (the major source of CO_2 emissions) have been fundamental to the industrial economy (see Figure 3), the debate over how to reduce global CO_2 emissions is more highly charged than was the debate over ozone. At heart, it is a debate between rich and poor, between developed and yet-to-develop countries, between North and South; it is a debate among different notions of justice and responsibility for the habitability of the earth and the socio-economic well-being of its inhabitants.

At the 1992 Earth Summit in Rio de Janeiro, the "real" nature of the debate was revealed when the US broke ranks with the Europeans and Japan on committing to CO_2 cutbacks, claiming economic hardship and scientific uncertainty. Likewise, China and other less developed countries felt that to freeze their CO_2 emissions at 1990 levels would freeze them in poverty. Although there is a broad scientific consensus about the basic principles and potentialities for global warming, debate continues over the evidence that ties current warming trends to CO_2, over the strength of the **negative feedback loops** that could rein in global temperatures naturally, and over other factors such as volcanic ash and aerosols that may be masking the CO_2-caused increases (for more detail, see Broecker 1992, and Liverman and Solem 1996). Buttel, Hawkins, and Power (1990) cite several other issues that could potentially erode support for the global change movement in general and climate change action in particular. If the problem is stated as a choice between, on the one hand, fossil fuels and CO_2 emissions and, on the other hand, nuclear power or huge hydropower projects like China's Three Gorges that disrupt ecosystems, flood scenic canyons, and displace hundreds of thousands of villagers, then opinions on climate change could easily polarize and paralyze the process of finding solutions.

Figure 3: Global CO_2 Emissions Rates, 1880-1990

(in 10^{15} g Carbon per year)



Source: Balling. 1992. *The heated debate*. San Francisco: Pacific Research Institute for Public Policy. Reprinted with permission of the Pacific Research Institute.

This section has focused on why we are interested in global changes and the forces that bring them about. Before we look at these forces more closely in Units 2 and 3, let's begin by examining the ways in which people think about the relationship between global population size and global environmental change. In fact, there is an on-going and heated debate in the scientific community about this relationship, and an understanding of the different positions will help you form your own opinion on the matter.

Background to the Population-Environment Debate[3]

Global change research has adopted a holistic *systems* perspective in the search for an explanation of *causality*. One element of this new approach is the focus on "driving forces" of global environmental change (Stern, Young, and Druckman 1992). Population is theorized to be a key driving force along with economic activity, technology, political and economic institutions, and attitudes and beliefs, in bringing about change in the global environment. This is indeed a more comprehensive and sophisticated conceptualization compared to the earlier *Limits to Growth* perspective, but how exactly these forces interact to produce global environmental changes remains to be explained for different social, cultural, and geographic settlings. Because these causal linkages are still unclear in detail, scientists and the press continue to let their biases influence their perspectives on causation. To understand the often-heated debate between those who do and those who do not believe that excess population growth is the major driving force behind pollution, environmental degradation, and global change, we need to learn to "read between the lines," i.e., to pick up on the underlying assumptions that authors make.

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[3] This section and the next are largely based on contributions by Robert Ford, and modified by the author.

Note for instance the following statement from a work by the U.S. National Academy of Sciences (Committee on Science, Engineering, and Public Policy 1992):

> The more people there are in the world, the greater is the demand put on resources to provide food, energy, clothing, and shelter for them. All these activities necessarily involve emissions of greenhouse gases.

A superficial reading of that statement -- and many others like it -- could be taken to mean that there is a *direct linear relationship* between increasing numbers of people and global greenhouse gas emissions. This is partially true, of course, but the story is much more complex.[4]

Why is it so important to understand the *causal linkages*? Aaron Sachs's (1994) answer is:

> The question of what exactly causes environmental degradation is so important because, as Harrison notes, *'the way we look at causes deeply affects the search for solutions'* (Harrison 1994: 233).

Sachs then goes on to state that human greed and consumption patterns are to blame for the degradation of the earth's resource base and the environment (Sachs 1994: 252). Whether you agree or not with that explanation is not so important at this time. **The critical point is to learn how to distinguish between often-competing perspectives, filter out hidden assumptions, and make up your own mind.**

In "making up your mind" you will need to include an assessment of *the facts* -- which includes both data and tested, quantifiable natural and social science principles -- and the *values* that come through in other qualitative explanations of human behavior or motivations which express particular philosophical or political perspectives on *the causes,* the *winners and losers,* as well as the proposed *solutions* in global change (see Figure 4).[5] As you read conflicting opinions or debate these issues with classmates, think about the nature of the disagreement. For instance, if there is agreement on the basic facts and values, but a disagreement on how they apply, then the disagreement is "computational" in nature and can be resolved by better solutions (conceptual, mathematical, engineering, policy, etc.). At the other extreme, two parties may come to a question from completely different cultural perspectives, with different life experiences, different core values and different facts at their disposal. In such cases, convincing the other involves *inspiring* them to look at the world in a whole new way.

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[4] See the excellent discussion of this "linkage" problem in the recent report by Robert Engelman of Population Action International (1994) entitled: *Stabilizing the atmosphere: Population, consumption and greenhouse gases*. Note particularly Section II: "Considering population's role" pp. 17-24. (See *Appendix* for information on where to obtain this publication.)

[5] And of course, even "facts" may be hotly disputed and contested, as they were, for example, in the "OJ Trial." You might refer to Figure 2 that helps clarify the difference between "facts" and "values" of various types and the problems they each bring. Even "facts" can be "fuzzy" and perceived differently under different circumstances by different people. This causes much of the conflict over environmental issues today.

Figure 4: Conflicts Matrix (Facts vs. Values)

(Inspire)	CULTURAL -Facts disagree -Values disagree	POLITICAL -Facts agree -Values disagree	(Persuade)
(Verify)	LEGAL -Facts disagree -Values agree	COMPUTATIONAL -Facts agree -Values agree	(Solve)

Source: Compiled and designed by Robert Ford;
also published in *GeoJournal* 35, 2 (February 1995).

So again, why is it important to learn how to evaluate and critique the "bias" behind the various explanations of the population-pollution relationship? It is important because people in a different place and time and social situation are dealing with different technology, affluence, history, social organization, economic and political systems, and attitudes and beliefs, which not only makes them view the population-pollution relationship differently (values), but makes the relationship itself work differently (facts). Furthermore, any attempt to analyze and explain "human driving forces" objectively is often confounded by philosophical and theoretical debates going back a long time. Sometimes the debate becomes emotional and prevents progress if those involved in the debate are unable to step back from their arguments and reconsider their basic differences in underlying assumptions. In the next section, we look at each basic perspective separately.

The Role of Population in Environmental Change: A Survey of Perspectives

Explaining the "population-environment nexus" (Ford 1995) has become a real growth industry in the natural and social sciences in recent years.[6] Several competing perspectives have arisen over the past three decades or so. Figure 5 (after Ford 1995) is an attempt to order these perspectives into a useful classification. The basic difference that needs to be clarified is between "external" and "internal" views. Internal views are represented in the four boxes in the upper left and are broken down into “collective” and “individual” perspectives on the vertical axis and “optimistic” and “pessimistic” perspectives on the horizontal axis. The commonality among the schools of thought within the four "internal boxes" is that *they all believe population factors are important*, whereas the “external” schools of thought don’t believe that population *per se* is a problem.

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[6] See for instance the special issue of *GeoJournal* (1995) edited by Ben Wisner and entitled: "Questioning development: Growth? - destruction? - sustainability?" and the issue of *Human Ecology Review* (1994)). Articles by authors such as L. Yapa, M. Miller, J. Ribot, S. Place, and J. Olson focus on a variety of cases around the world; they question the conventional wisdom on development as well as Malthusian approaches to population-environment relations. Most fall within the "political ecology" school of thought in geography and anthropology. The special issue of *Human Ecology Review* (Summer/Autumn, No. 1, 1994) included a reprinted article from the *Amicus Journal* (Winter 1993) by Paul Harrison entitled: "Sex and the single planet: Need, greed, and Earthly limits." Ten

Let’s look first at the 2x2 classification scheme for the four internal boxes. The vertical axis distinguishes between two kinds of explanations for how global change comes about, namely as a result of many *individual* decisions and actions or as a result of *collective* (group) decisions and behaviors. According to the individualist thinkers, the processes that are important are those that govern the decisions by individuals, couples, and firms regarding desired numbers of children, consumer choices, what to produce and how to produce it, etc. According to collectivist thinkers, population and pollution are driven not so much by the sum of countless individual decisions, but by aggregate/group processes, like class, race, and gender conflicts. These thinkers also focus on the rules of the game in which individuals operate -- rules that are themselves the results of conflict between groups. The horizontal axis distinguishes between optimists and pessimists, who are divided by their outlook on our ability to solve the population-environment problems.

The Optimistic/Individualist Perspective

With this basic scheme in mind, let’s now look at the contents of the four internal boxes. The “optimist/individualist” perspective is most associated with “laissez-faire” economists such as Herman Kahn and Julian Simon (1981). They believe that *individual* producers, consumers, and families, aim at making optimal decisions for themselves and thereby also do what is best for the entire society. They are optimistic that the “invisible hand” of the free market will solve any shortage of food, energy, raw materials, pure water, and clean air, simply by people doing what is in their own best interests. Simon, for instance, points to historic examples of energy crises that were feared to be a result of overpopulation but did not materialize. In the 1800s, people worried that wood for heating and whale oil for lighting would run out because of overpopulation, but these fuels were replaced by coal and gas, which were mostly replaced by oil before the coal and gas ran out. Likewise, he points to the long-term historical decline of real (inflation-adjusted) prices of natural resources like grain, copper, and oil to argue that there is no scarcity of these goods. On the contrary, in his view they are actually becoming more plentiful,

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issue of *Human Ecology Review* (Summer/Autumn, No. 1, 1994) included a reprinted article from the *Amicus Journal* (Winter 1993) by Paul Harrison entitled: “Sex and the single planet: Need, greed, and Earthly limits.” Ten invited articles then responded to the article. The articles essentially “covered the bases” on various viewpoints on “population-environment” relations: from Malthusian to Cornucopian. Paul Harrison expands his variation of Holdren and Ehrlich’s I = PAT formula, and calls it I = PCT instead.

despite the doubling and redoubling of the world's population. The primary explanation for these optimistic results is the free market and the role of prices as signals to *individual* producers and consumers. A resource scarcity causes the price to increase, which in turn triggers a whole variety of responses by individual producers and consumers that cause the scarcity to disappear. The price increase triggers substitution away from that scarce resource, induces technological change in order to increase the efficiency of how we produce and consume a resource, and encourages increased exploration to find more of it.

Figure 5: Perspectives on Population Issues and Theory

PROBLEM-SOLUTION ORIENTATION

EXPLANATION OF CHANGE	OPTIMISTIC	PESSIMISTIC	EXTERNAL
INDIVIDUAL	Technocrats Traditional Capitalists and Business Elites Right-to-Life Groups	Neo-Malthusians Family Planners UNFPA / Planned Parenthood	Problems and Solutions are Incorrectly Defined Old Left & New Right
COLLECTIVE	Old Line Communists; Marxists/Neo-Marxists Catholic Action Groups Some Feminists -"Empowerment" Advocates Boserupians- "Agricultural Intensification" - Technocrats	The "Ecologists": e.g. Ehrlich, Hardin Gaia - "Earth First" Advocates / Radical Greens Some "Ecofeminists"	Problems More Fundamental than Population Require Solution Militant, Radical Groups Violent Revolutionaries
EXTERNAL	Problems are Self-Regulating Solutions are Unnecessary	Problems are Part of the Nonrational World Solutions are Impossible Existentialist Fatalist Escape/Apathy Culture	Problems Do Not Exist Solutions Would Create More Problems Conservative Nationalistic Elites

Source: Compiled and designed by Robert Ford; also published in *GeoJournal* 35, 2 (February 1995).

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The individual/optimistic perspective also sees population growth as a good thing because it spurs economic growth, which is believed to cure all ills. The argument goes like this: if there are more people, there are more consumers to buy more goods, produce more GNP, and hence to alleviate economic hardship. Some optimists also believe that a larger global population, in and of itself, will hasten technological innovation, because more people means more thinkers, more "human capital" to bank on. These various arguments comprise the classic **Cornucopian perspective**, named after the biblical horn of plenty.[7]

The Pessimistic/Individualistic Perspective

The pessimistic/individualistic perspective focuses on individual actions as the key driving force but believes that what is good for individuals rarely corresponds with what is good for the planet, a situation that leads to the "**tragedy of the commons**." The *commons* refers to renewable resources that are available to be used by a collective of people, that is, a publicly owned resource. The *tragedy* is that it is to the private advantage of individual users in the short term to maximize their use of the common resource, even if doing so has the result of diminishing the total yield or destroying the resource altogether in the long run. The "tragedy of the commons" was first described with regard to overgrazing community pastures and the like, but the concept applies equally to destroying the ozone layer, damaging the global climate, over fishing a species to the brink of extinction, ocean dumping, and so on. In short, actions that are in the short-term self-interest of individuals, firms, or families add up to harmful consequences for society and the environment. This view constitutes the "neo-malthusian" perspective.

The pessimistic/individualistic school proposes individually oriented solutions to population-environment problems. On the population side, the primary solution is family planning, which includes distributing contraceptives and education and counseling as to why a smaller family may be a richer, better educated, and healthier family. Some proponents of this view also support individualistic incentives for smaller families, such as social security systems that reduce a person's old-age payments if he or she has more than two children.

On the resource/environment side, the pessimistic/individualist school of thought emphasizes fixing the market system so it will send the right price signals to individuals and firms. The tragedy of the commons occurs because clean water and air, pristine animal habitats, ocean resources, the ozone layer, and other environmental "goods" do not have a market price. Instead, when they are degraded, they cause "environmental externalities" or "social costs." These are real costs to society as a whole, but they do not have to be paid for by the company or individual who is causing the degradation. Thus, the cost is "external" to the perpetrator of the environmental impact. The social costs of air pollution, for example, include more sick days for workers because of respiratory problems, greater health care expenses, more frequent building signal to society for triggering technological, economic, and behavioral solutions to environmental problems, just as rising oil costs triggered the development of more efficient automobiles. Those in the field of environmental economics, however, feel that the market will not trigger the correct responses to social costs unless they are charged to the individual users in the form of emissions taxes and the like. For these reasons, the US has instituted a "market" for permits that allow power plants to emit SO_2, and many European countries charge high taxes on gasoline and, more recently, on CO_2.

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[7] Lindsay Grant, in an article entitled "The Cornucopian Fallacies" (1993), rebuts these arguments one by one. She states that the declining real price of most natural resources is caused by greater labor productivity resulting from the substitution of capital for labor -- not by a greater abundance of copper, grain, or oil.

One of the key reasons for this group's continued *pessimism* is the long delay in the chain of events that would enable the free market to solve environmental problems. Social costs take time to grow large enough to spur action. Then, scientists must take time to clearly identify the causes and the effects. Finally, the political system takes time to develop a consensus to either regulate the activity or charge the social costs to those who benefit from the activity. Only then will the market economy start developing technological solutions to the problem, and these in turn will take quite a while to innovate, diffuse, and take effect.

The Pessimistic/Collectivist Perspective

The "pessimistic/collectivist" perspective includes those who decry the impact of growing populations as aggregate entities and worry about the impact of such growth on resources, jobs, security, air, and water. Population is definitely a "problem," but they generally have little faith that humans will act for the benefit of the whole. This group includes "Social Darwinists" and many of the radical "Earth First-ers" who not only see procreation as a problem, but also blame a materialistic society manipulated by advertising and a "military/industrial complex" that profits from everything from war to consumerism. Ecofeminists, though not uniform in their outlook, tend to see environmental degradation and overpopulation as a result of patriarchal power relationships in society. Another often-related, pessimistic, collective view holds that poverty, overpopulation, and environmental degradation go hand-in-hand in the Third World and are the result of neo-colonialism by multinational corporations. And Marxists would trace it to the evolution of global capitalism in the late twentieth century. The commonality in this diverse group is the pessimistic belief in a "Hobbesian" outcome that must be blamed on one or more particular groups in society.[8] The solutions offered by these schools of thought -- if they see any --sometimes have anarchic and revolutionary outcomes but generally call for fundamental changes in the structure of society, i.e., the relationships between different social groups that govern their interactions with each other and with their environment.

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[8] Hobbes was a seventeenth Century political theorist who described people as selfish and life as "nasty, brutish and short."

The Optimistic/Collectivist Perspective

The optimistic/collectivist school also focuses on broader social class/group factors but sees them working toward a rosier future. In support of its view, this group focuses on the advantages of "mass power" for creating armies, political action, Utopian societies, etc. Many traditional Marxists fall into this category, with their focus on the "power of numbers" and the labor theory of value.[9] The father of Chinese Communism, Mao Zedong, for example, was fond of saying "two hands can produce more than one mouth can eat." He proposed "winning against the West" with procreation and mass power. This particular point of view is now largely unpopular.

The optimist/collective perspective also includes feminist empowerment advocates, who tend to see environmental damage resulting from the low status of women in many Third World countries. If women received equal education, equal access to start-up capital, and had more say in how many children they have, then many of today's problems could be avoided. Many demographers and population policy planners tend to concur with this perspective. Optimistic collectivists tend to favor solutions that focus on broad social/economic policies and interventions.

Understanding all the "external" boxes follows from the above basic distinctions. In all cases their explanations fall outside population forces as the dominant variable. They may see other causes or issues as equally or more critical, such as economic growth, national self-determination, development, or instituting and maintaining religious law in a theocracy (a government subject to or ruled by religious authority). Because they see these concerns as more important, they tend to dismiss population concerns. In other words, if they are pessimists, they are pessimistic for reasons other than population per se. Some believe humans are intrinsically flawed in their values or genetics. Fatalists believe that solutions cannot be found because the problems (whatever they may be) lie outside the realm of human understanding or influence, e.g., fate, cycles of the universe, etc. They might claim "God/Allah wills it," and there is nothing we can do about it. In all these external viewpoints, the key is to recognize that they fall into the "humanist/existentialist" philosophical arena. These perspectives are not commonly heard or discussed by mainstream scientists or demographers or other social scientists with an activist/interventionist perspective.

As you read about global environmental change in this module, try to see where the authors are coming from. What is their perspective on the *causes* and the *solutions*? Place the authors in this external/internal -- individualist/collectivist -- pessimist/optimist grid. This will help you understand the authors' claims and their arguments against other people's claims.

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[9] Marxists argue that the value of goods reflects the amount of labor time involved in their production (i.e., there is no intrinsic value to goods and services). Capitalists obtain profits by exchanging goods and services at a higher price than they pay for labor.

An Alternative Classification of Perspectives

This classification of perspectives is not the only one currently discussed in the literature. A different way of categorizing the scientific literature on population-environment relations has been proposed by researchers at the Carolina Population Center (Marquette and Bilsborrow 1994). They suggest that three perspectives can be distinguished in current research and conceptual thought addressing population-environment relationships (Figure 6). These perspectives differ according to whether the relationship between population and the environment is *direct and linear, multiplicative and synergistic,* or *mediated by intervening factors.*

Figure 6: An Alternative Classification of Perspectives on the Population-Environment Relationship

1. The relationship between population and the environment is ***direct and linear***
    a. Malthusian — pessimistic
    b. Boserupian — ↕
    c. Cornucopian — optimistic

2. The relationship between population and the environment is ***multiplicative/synergistic***
    a. $I = P \times A \times T$ and variations thereof
    (I = Impact, P = Population, A = Affluence, and T = Technology)
    b. Quantitative Systems Dynamics

3. The relationship between population and the environment is ***mediated*** by social, institutional, cultural, economic, and other factors.
    Examples: Political ecology approach; recent vulnerability research in Geography.

Source: Adapted from Marquette and Billsborrow (1994: 4).

The Direct/Linear Perspective

Direct/linear thinkers range from pessimistic (i.e., more people on Earth leads directly to more environmental degradation) to optimistic (more people leads to more of the good things people do, such as innovation). The Malthusian position -- originating in the eighteenth century from the somewhat pessimistic writings of Thomas Malthus (Malthus 1960 (c1798)) -- has had a particularly strong influence on the development of the concept of **carrying capacity**, which implies that the ability of land to produce food is limited and that exceeding those limits will result in degradation and the possibility of social or ecological collapse.

Many global change thinkers use the concept of carrying capacity (Marquette and Bilsborrow 1994: 7-9). Demographers and human ecologists, range scientists, and biologists try to find the *optimum population* for an ecosystem or region, e.g., the "livestock units" threshold of a given rangeland. Researchers interested in defining carrying capacity emphasize linearity and equilibrium within systems (Hawley 1986; Drummond 1975). Recently non-equilibrium models have become more common in the social and natural sciences, much of the impetus coming from chaos theory. Some good examples are the works by Zimmerer (1994) and Turner and Benjamin (1994) who apply these new concepts to cultural ecology and agriculture.[10] Another example of how population growth is linked to carrying capacity is the *Carrying Capacity Network Focus* newsletter which carries many provocative articles, often by renowned activists.[11] The concern with carrying capacity is at the root of the concept of overpopulation, e.g., the situation in which the number of people per unit of land exceeds its carry capacity. Those who particularly blame overpopulation for most environmental ills, such as Paul Ehrlich -- founder of the organization *Negative Population Growth* -- have come to be known as *neo-Malthusians* because they use modern research methods but generally share Malthus's pessimistic view of society's ability to make the changes necessary to live in balance with nature.

A variation of the direct/linear perspective -- the **Boserupian perspective** -- originated in work of the agricultural economist Ester Boserup (1965, 1976, 1981). Boserupians are more optimistic than Malthusians in that they suggest that technological, economic, and social innovations induced by "population pressure" can lead to what agricultural specialists call *intensification of agriculture*. For example, Hyden, Kates, and Turner (1993a, 1993b) test the intensification concept with data from ten case studies in Africa, all in regions with *high population density*. Their purpose was to consider what was driving the "intensification" process, whether it was reaching some limits, and whether other scenarios, e.g., **degradation** or **agricultural involution** were also evident at the same time. They found a complex set of drivers of intensification, although the demand emanating from population was an important one. In most cases, intensification was proceeding and land degradation or involution was occurring where structural barriers inhibited sustained land improvements. The Boserupian school of thought has been influenced by neo-liberal economic theory, "induced agricultural development" theory, and by proponents of agricultural changes like the **Green Revolution**.

A more *optimist* school of thought, which does not see population as having *any* negative impacts, are the *Cornucopians* and Marxists, whom we discussed earlier. Karl Marx -- a thinker of the nineteenth century succeeding Malthus -- focused almost exclusively on class relations as the underlying explanation for social exploitation, but he said little about degradation of the physical environment. Many modern *neo-Marxists* do see the environment as an important issue, but they still emphasize collective "political-economic" variables for explaining environmental degradation.[12]

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[10] The latter work by Turner and Benjamin (1994) has an excellent discussion of the concepts of "fragility and resilience" in ecosystems and their varieties within high and low-potential regions.

[11] The article by Paul J. Werbos (1993) entitled "Energy and population: Transitional issues and eventual limits" as well as the one by Lindsey Grant (1993) entitled "The Cornucopian fallacies" are good examples of this type of thinking; both authors are activists at the grassroots level. (For contact information see *Supporting Materials*.)

The Multiplicative and Synergistic Perspective

The second perspective described by Marquette and Bilsborrow (1994) is the ***multiplicative and synergistic*** approach. Basically, this approach sees population variables such as growth, size, density, and distribution interacting in a multiplicative way with other factors such as consumption and technology. It suggests that while population, consumption, and technology might be seen as independent causes of environmental impact, emphasis should be put on the combined *aggregate effect* of these factors. Many thinkers in this group could be characterized as *collectivists* who are also *neo-Malthusian/pessimists*. This approach is most often associated with the **I = PAT** formula created by Holdren and Ehrlich (1974) (see also notes in Figure 4). I = PAT (commonly pronounced as "Eye-PAT") is the mathematically formulated shorthand for environmental **I**mpact equals **P**opulation times **A**ffluence times **T**echnology. The thinking is multiplicative in the sense that 10 people each using one ton of coal has the same impact as one person using ten tons of coal. The *Limits to Growth* world systems computer model can be considered a much more sophisticated mathematical approach to the multiplicative idea. (For a discussion of the quantitative systems dynamics approach, see *Supporting Material 1b*.)

The multiplicative approach has been criticized by some as being too impersonal and ecocentric: it tends to puts "saving nature before people" and it does not disaggregate the important political, cultural, and institutional variables that cause people to degrade their environments (Shaw 1992, 1993; Lewis 1992). Nevertheless, the I = PAT formula is used frequently by global change researchers, e.g., Dietz (1994); they find it to be a useful framework for quantifying global environmental change processes. Most, however, try to avoid the more extreme "radical Green" philosophies held by some within this school of thought (e.g., Lewis 1992). Paul Harrison's article "Towards a post-Malthusian human ecology" in the *Human Ecology Review* (1994) presents a well-reasoned and balanced use of the slightly altered **I = PCT** formula (where "C" stands for **C**onsumption).

The Mediating Approach

The third perspective, the **mediating approach**, is a variation on the multiplicative perspective which tends to be more *anthropocentric*. Those within this school adopt an approach that attempts to integrate both natural and social science forces. They put a much stronger emphasis, however, on the human dimensions and the interactions of social organization, culture, institutions, the political-economy, and nature. They also reject simplistic Malthusian arguments and argue instead for a focus on "context." For instance, Ford (1995) points to the fact that when famine struck Burkina Faso in the 1980s and Rwanda in the 1990s, many scientists and journalists immediately ascribed it to overpopulation. As Ford points out, however, the crisis in Burkina Faso had to do with a global recession's effect on the export-oriented coastal economies, leading to migration back to homes in the interior. The interior, in turn, could not compete with the influx because an ethnically based revolution had destroyed traditional problem-solving systems.

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[12] See e.g., Adams (1990) for a historical analysis of the various perspectives on environment and sustainability.

An example of the mediating approach within geography is the **vulnerability** research done by Hans Bohle, Michael Watts, and Thomas Downing (1994). Here, the emphasis is on who is most vulnerable to disasters, hazards, or the negative effects of global change. This approach owes much to the tradition of "hazards" research within geography as well as to the cultural and political ecology perspectives in geography and anthropology (Bryant 1992; Adams 1991; Palm 1990).[13]

In sum, the mediating approach puts the emphasis on "*who are the winners and losers* (actors) in the *human-environment interactive processes* involved in global and local *adaptation and response* to environmental change." It looks at the environment from a systems perspective but also shares some methods and ideas of "political economy." In fact, this approach goes beyond political economy by placing much more emphasis on *human agency*. An increasingly important goal of "mediating" theorists is not only to explain but to find solutions. Thus, in recent years, they have considered the *policy dimensions* more and more; many have moved beyond explanation and into the arena of *advocacy* (e.g., Arizpe, Stone & Major 1994; Bilsborrow and Geores 1993).

So What?

Though sorting out "who is in what school" may seem difficult, it is important. Why? To become an *informed consumer* of the many ideas and solutions proposed is considered by some to be a basic responsibility, not only of the scientist but of any member of society. To repeat what Paul Harrison said: *"the way we look at causes deeply affects the search for solutions"* (Harrison 1993, 1994: 233).

The above sections on the "population debate" tried to show that the population-environmental degradation problem is more than a "scientific" question, but a basic question of "values." When we understand "where people are coming from" we are in a better position to judge the true merits of what they argue and propose. And when we do research, we will be in the knowledgeable position to ask the kinds of questions that are most likely to produce useful and humane as well as plausible answers -- questions that matter for policy-making and theory-making. And finally, we may even think or behave differently!

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[13] Some of the writers in this camp bring to bear a *neo-Marxist* perspective in combination with classical natural and social science systems theory and methods (more generally, these fall within the wider tradition of "nature-society" studies in geography). Many of those who published in the special 1995 *GeoJournal* issue cited above, e.g., Wisner, Miller, Yapa, Olson, Ribot, Ford, Cummings, and others exemplify this perspective. The IGU Commission on Critical Environmental Situations and Regions also qualifies as a proponent of this more anthropocentric perspective (see e.g. Kasperson, Kasperson, and Turner 1995). The classic work in political ecology by Blaikie and Brookfield (1987) as well as a more recent book by Blaikie, Cannon, Davis, and Wisner (1994) also fit into this perspective.

In the following units we introduce some basic demographic and economic concepts that will allow us to understand the forces that drive the scale of the human economy ever higher. After exploring population growth (Unit 2) and energy use (Unit 3), we will look at how the global volume of emissions is linked to population and energy (Unit 4).

1 Human Driving Forces of Global Change

Instructor's Guide to Activities

Goal

The activities in Unit 1 are designed to provide students with a basic understanding of population, wealth, environmental issues, and the patterns and interactions among these concepts. The instructor may introduce specific topics here and build on them later in the module. Activities 1.3 and 1.4 allow students and instructors to determine the levels of student understanding of global patterns of population, wealth, and environmental problems.

Learning Outcomes

After completing the activities associated with this unit, students should be able to:

- take "good" notes on readings;
- produce and read simple thematic maps;
- recognize and discuss differences in perception; and
- recognize regional differences in environmental problems and population patterns.

Choice of Activities

It is neither necessary nor feasible in most cases to complete all activities in each unit. Select activities that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

1.1 Starter Activity -- Questions for a class discussion
1.2 Taking Good Notes -- Text comprehension and note taking
1.3 What Do You Know About Your World? -- Thematic mapping, analysis of personal assumptions and perceptions of the world
1.4 Environmental Problems the World Over -- Thematic map reading and interpretation
1.5 The World Is Your Classroom -- Visualizing the global distribution of population or wealth

Suggested Readings

The following readings accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

- Unit 1: The human driving forces of global change (provided)
    The background information to Unit 1 (all students should read)
- Clark, William C. 1988. The human dimensions of global environmental change. In *Towards an understanding of global change. (Initial priorities for U.S. contributions to the International Geosphere-Biosphere Program)*. Washington, DC: Natl. Acad. Press.
- Kotlyakov, V.M. *et al.* 1988. *Global change: Geographical approaches (A review)*. Proc. Natl. Acad. Sci. USA, vol. 85, pp. 5986-5991.
- Buttel, Hawkins, and Power. 1990. From limits to growth to global change. *Global Environmental Change* 1: 57-66.
- Any introductory human or world regional geography text should also provide a global overview of population, wealth, and environmental issues.

Preparation for Module Activities

You may choose early in this module to assign students or groups of students a set of countries to consider throughout the entire module. This will encourage students to relate what they are learning throughout the module to particular areas of the world. It will also prepare them for several activities in Unit 4 which require them to look closely at a set of countries as a group. For a list of suggested country groupings, see the Unit 4 Instructor's Guide to Activities.

Activity 1.1 Starter Activity/Questions

Starter Activities and/or questions are designed to capture the students' attention, to recall their pre-existing knowledge on a subject and give them an opportunity to use expressive language, to engage them with the subject, and to stimulate their thinking with provocative statements. Using the responses that students provide to these questions, the instructor can guide the discussion to help students make links between their responses and the various perspectives that were considered in Unit 1. (See also Activity 4.2 for an activity that incorporates the various perspectives on the relationship between population and the environment.) These questions can also be used when class discussion lags. Here are some suggestions (add or adapt this list as you deem necessary or appropriate for your class):

- Why do you think women in the Third World generally have more children than women in this country?
- What are the effects of having more and more people living on this earth? (If this question causes difficulties, instructors may help students with suggestions like: imagine New York City had 40 million inhabitants, or: if our town [fill in] was three/five/ten times bigger than it is now, how would it look? How would you feel about it? What kinds of problems do you think we would have then?)
- Look at the four cartoons on the overhead/handout (overhead/handout original provided in *Supporting Materials 1.1*) -- what do you think of them? Do you agree or disagree with the messages they convey? How so? Have you heard these arguments before? From whom?

- Do you think the earth has any environmental limits? What would they be? Similarly, do you think society has limits, such as a maximum number of people or a minimum amount of resources necessary to keep it functioning? If you feel there are limits, what would they be?
- What do you think would bring down resource and energy usage more: curtailing population growth in the Third World or reducing resource and energy use in the First World? Why do you think so?
- Why should it matter whether or not I turn off the lights when I leave a room for half an hour -- when during that same time hundreds of people are born in the Third World? Why should I bother saving energy? The problem is not burning one light bulb but that there are just too many people on this earth!
- How much energy is there in the world? Do you think there is enough to go around for all of us that currently live on this planet?
- Would there be enough if everyone on earth used as much energy as the average American or European?
- Would there be enough for twice the current population (about 5.7 billion people)?
- Where does the electricity come from for your home? Where does the gas come from to run your car?
- Where in your daily life do you think it's feasible for YOU to save energy?

Based on this last question, the instructor may consider the following exercise to extend this activity. After students have made a short list of feasible ways in which they could alter their own resource consumption behavior, ask them to commit to changing just one thing in their daily life that would reduce their energy consumption. They should keep a diary for 1 to 4 weeks in which they write one 100-word paragraph every day reporting on their progress. Ask students to be honest with themselves, and be certain that they understand that they aren't keeping this progress-diary to impress you (the instructor) but just to observe how difficult or easy it is for them to change one thing. At the end of the diary-keeping period, you could ask them to hand in their diaries, write a longer paper summarizing their experiences, or initiate a class discussion of them.[14] (See also Activity 3.5, Alternative 1.)

Activity 1.2 Taking Good Notes

Goals

In this activity, students learn to take clear, pertinent, and concise notes on assigned readings. The activity is introduced early on, but students should make note taking a regular habit throughout the module and the course.

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[14] This activity is adapted from one conducted -- with great success -- by Kirstin Dow, University of South Carolina, Columbia.

Skills

✔ note taking
✔ critical text comprehension

Material Requirements

- *Student Worksheet 1.2* (provided)
- *Supplementary Material 1.2* (provided)
- Suggested or alternative readings

Time Requirements

Variable (depending on length of chosen readings and students' skill levels)

Task

Students learn with the help of guiding questions and the help of their instructor, how to take good notes on their readings, i.e., they learn to discern the structure of a text, and subsequently to structure their own notes, to paraphrase the main argument(s), and to distinguish "important" information from "text fillers."

A hand-out on note-taking is provided in *Supporting Material 1.2*. Students should be encouraged to use it as a "standard" exercise which they do automatically as they read assigned class material. The time required varies with the length of the readings and students' reading skills and ease with the material. Instructors should choose readings accordingly.

Activity 1.3 What Do You Know About Your World?

Goals

In this activity, students learn how to interpret and design thematic maps and to critically evaluate their perceptions and assumptions about the world.

Skills

✔ transfer a perception of the world (a mental image) onto a map (an actual image)
✔ produce a rough but logically coherent thematic map of an indicator of choice (e.g., population, wealth)
✔ critique classmate's perceptual map
✔ recognize and discuss differences in perception

Material Requirements

- blank world map showing nation-state boundaries (provided in *Supporting Material 1.3* to copy for your class)
- color markers

Time Requirements

20 minutes

Tasks

The instructor distributes copies of the world map to all students. Then she or he proposes one variable, like population (as absolute numbers, growth rates, density etc.), wealth, or energy usage. It is not necessary to provide definitions of "wealth," or to predetermine what form of energy is used, but it might be helpful to decide on the kind of population variable used.

Ask students to display in some logical fashion how the chosen indicator varies across the globe. If your students are unfamiliar with thematic maps, display a prefabricated example, or develop one with the class, on an overhead projector. In the latter case, you might take a show of hands as the impressionistic basis for determining which regions of the world in students' opinion rank higher and which lower in that particular indicator. It is easier and sufficient for this exercise to limit yourself to three categories; use color sequences (e.g., yellow/orange/red) or different densities of black dots (low/medium/high) to illustrate the ranking.

After about 5 minutes during which students draw their thematic map according to their perceptions of the world, have them exchange their map with that of a neighbor, take a few minutes to think about this other map, and then have them take turns telling each other what they thought about it. The instructor may go around the room and pose questions like "what does "wealth" mean to you? How does that affect how you drew your map?" or "why did you put [country x] into this category rather than in that?

Finally, show them a world thematic map that displays the chosen variable based on actual data. Explain what data the map was based on and explore with students how their maps differ from this map. Be careful not to intimidate students with "perfect" looking maps, or "real data;" instead, validate students' perceptions by asking why they drew something a certain way. This question will help them name their underlying assumptions. Help them see (now and throughout the remainder of this module) how underlying assumptions color one's perceptions of the world, one's choice of data, methodologies, and explanations.

(Alternatively, this exercise could be done in pairs and discussed later with a neighboring pair.)

Activity 1.4 Environmental Problems the World Over

Goals

The purpose of this activity is for students to become proficient at reading thematic maps. As a part of this activity, students will identify relationships between environmental problems and their human driving forces.

Skills

✔ reading thematic maps
✔ recognizing regional differences in types and severities of environmental problems

Material Requirements

- *Student Worksheet 1.4* (provided)
- World environmental atlases or maps; examples include:
  - -C. Novosed (ed.) 1994. *The Nystrom desk atlas*. Chicago, IL: Nystrom (with a good map of environmental degradation).
  - -Joni Seager. 1990. *The state of the earth atlas*. New York: Simon & Schuster.
  - -Joni Seager & Ann Olson. 1986. *Women in the world atlas*. New York: Simon & Schuster (with great examples on population related issues)
  - -Alan Thomas. 1994. *The Third World atlas*. Washington, DC: Taylor and Francis (has a thematic map on environmental concern which includes acid rain, desertification, rain forest, coral reefs, plus many related maps of population, industry, famine, and so on)
- alternatively: local, regional, or US maps on module-related issues if possible (population, specific environmental problems, wealth, energy usage, etc.)

Time Requirements

15 minutes in class, or longer if done as homework

Tasks

The instructor explains some basic skills of reading thematic maps (what is shown? what do the different colors/patterns mean? what does that say about [region x] or [region y]? -- first descriptive, then analytical, then explanatory). Let students work in groups or pairs to describe and explain to each other what they find on the map: What environmental problems does a particular region confront? What are some probable reasons that we can find on the map or accompanying maps (e.g., a map of industrial installations, or population density as background to water quality issues)? How does that compare to another region? Which environmental problems seem to be related to population pressure on the land and which seem to be more driven by wealth (or poverty) and industrial (or agricultural) activity? etc.

If this activity is done as homework, the instructor may ask the students to write a 1-2 page summary of their observations. This summary could be written in various genres: a personal letter, a newspaper report, or a business briefing to a chosen audience.

Activity 1.5 The World is Your Classroom

Goals

In this activity, students visualize and experience the unequal distribution of population, wealth, and resources around the world. Students will also distinguish between total, percentage, and per capita data.

Skills

✔ visualization of global distribution patterns of population, wealth, etc.
✔ determining proportions (calculating the number of students per continent for each variable)
✔ expressive writing and oral expression

Material Requirements

- Chairs in sufficient numbers for a proportional representation of population per continent (alternatively or additionally, use chalk or tape to mark off continents on the floor; or use floor tiles to delineate continents according to their size)
- *Supporting Material 1.5* (provided)

Time Requirements

10 minutes; longer time required for classes of 70 or more individuals. Add 5 minutes for each additional variable used in the activity.

Tasks

Designate areas in the classroom (chairs, floor tiles, etc.) to be proportional to the area of the earth's continents (if you have enough time, assist students in figuring this out; examples for varying class sizes are given below):

Table 1: Continental Land Area Data

Continent	*Percent of Land Area*	*No of chairs (total of 20)*	*No of chairs (total of 30)*[1]	*No of chairs (total of 50)*[1]	*No of chairs (total of 70)*	*No of chairs (total of 100)*[1]
Africa	20	4	6	10	14	20
Asia	29	6	9	15	20	29
Europe	7	1	2	4	5	7
N America	16	3	5	8	11	16
S America	14	3	4	7	10	14
Antarctica[2]	9	2	3	5	6	9
Oceania[3]	6	1	2	3	4	6

1 -- does not add up to class size because of rounding 2, 3 -- optional

Assign students to these areas in correct proportions so that the class visually represents world population. In 1996, the world's estimated population of 5.7 billion is divided among continents proportionally as follows:

Table 2: Continental Population Data

Continent	*Population (millions)*	*Population (%)*	*No of studs. (class of 20)*[1]	*No of studs. (class of 30)*	*No of studs. (class of 50)*[1]	*No of studs. (class of 70)*	*No of studs. (class of 100)*[1]
Africa	732	12.7	3	4	6	9	13
Asia	3,501	60.7	12	18	30	42	61
Europe	728	12.6	3	4	6	9	13
N America	458	7.9	2	2	4	6	8
S America	323	85.6	1	2	3	4	6
Oceania[2]	29	0.5	0	0	0	0	1

1 -- does not add up to class size because of rounding   2 -- optional

Once students are assigned to the "continents," allow a moment for them to visually understand the concept of population density. Some students might be reserved and added to the continents in 10-year steps to represent future population growth.

Now visualize other variables in proportional fashion. You may demonstrate variables like wealth (e.g., as gross domestic product, or percent of television sets in that population), energy usage per capita, calories of daily food intake, etc. Use pennies, candy, matches, a cake divided in correct proportions to illustrate the point. Students might also be directed to sit in one corner of the continent representing the correct proportion of the population that belongs to a certain religion, or ethnic or language group, or group that received formal education, etc. See *Supporting Material 1.5* for a list of examples with their proportional global distribution.

Then give students 5 minutes to write down their impressions of what they just experienced (see *Notes on Active Pedagogy* on little writing exercises in class) and finish off the activity by asking them to share what was most impressive for them, what was new to them, or what they learned.

Alternative version: This exercise is more easily done and more impressive with larger classes. For small classes, the same learning outcomes can be reached by adopting this exercise as a board game. Put a large piece of paper with an outline of the earth's continents on a table around which your students gather. Exact shape of the continents is less important than close-to-correct representation of their relative sizes. Use proportional numbers of pebbles, paper cups, birthday candles, etc. to represent world population. Then use similar objects as mentioned above to represent proportional distribution of other variables, like wealth, energy usage, education, daily food intake, etc. The write-and-share exercise is the same as described above.

1 Human Driving Forces of Global Change

Student Worksheet 1.2

In this set of activities we will look at some of the issues touched upon in the Unit 1 *Background Information* that you read. You will tap into what you already know about population, wealth and environmental issues; you will look at some maps to discern global distribution patterns of population and wealth; and you will begin to understand the relationships among population, wealth, and the environment. But first, let's learn something real basic ...

Activity 1.2 Taking Good Notes

As you work through the reading assignments for this course, do not just read the articles, or just underline important passages. For understanding and remembering the arguments, it is even more important to take notes on what you read. The primary purpose of taking notes is to produce a brief overview of a text to help your memory recall the big picture.

Refer to the hand-out provided by your instructor on how to take good notes so you can follow and better understand the six steps of note taking listed below!

Steps in taking notes on your readings:

1 **Gather the most obvious clues!**
2 **Put your mind's antennas out!**
3 **Read the text (again)!**
4 **Note the main argument!**
5 **Concisely list the supporting arguments under each heading (or subtitle)!**
6 **Check whether it makes sense!**

Student Worksheet 1.3

Activity 1.3 What Do You Know About Your World?

What do you know about the world? Well, you be the judge, but you probably know more than you think! Even if we *think* that we don't know all that much, we might still have a hunch, an inkling, a certain perception of the world, and what happens in it. This exercise is exactly about your perception.

Your instructor gave you a blank world map and you have decided on one indicator of, say, population, wealth, or energy usage that varies across the globe (an indicator that varies across time or space or social groups and so on is called a *variable*). Your task now is to show how *you* think this indicator varies globally. Don't worry about exact numbers or even whether you're going to get it exactly right. For now all that counts is how you think the global picture looks.

In order to simplify things a little bit, let's categorize countries as falling into one of three categories: those in which your chosen indicator is high, those in which it is low, and those in which it is intermediate. Then choose a color with which you will represent each category, and color the map. For example,

VARIABLE	*CATEGORIES*	*COLOR*
wealth	high	red
	intermediate	orange
	low	yellow

You might feel as if you're back in grade school, but in fact what you are just about to do is called *thematic mapping* because you are transferring a theme (e.g., wealth) that varies by region onto a map. Granted we are not producing fancy Rand McNally maps; instead, we are making maps of our perceptions of the world. Such maps are called *mental maps*, and they are very important starting points in understanding our environment. In fact, you may be surprised in a minute to see the mental maps of the world with which your classmates begin this class!

When you're finished with your map, exchange maps with one of your neighbors. Take a few minutes to study your neighbor's map -- how does it differ from yours? What surprises you about this map? How does your neighbor understand the indicator (wealth in our example above)? Take a few minutes to tell your neighbor what you thought about his/her map and hear what he/she has to say about yours. Ask each other what you thought of when you heard "wealth" (or whatever variable you used). What general conclusions can you draw from this exercise about:

- How perception relates to the maps you drew?
- How perception affects *your* understanding of the world and its problems?
- How perception affects *anyone's* understanding of the world? and
- How perceptions (and assumptions) affect our research of global problems?

Student Worksheet 1.4

Activity 1.4 Environmental Problems the World Over

In this activity you will learn to read thematic maps, maps that show how one theme -- the problem of acid rain, or the loss of wetlands, for example -- varies across space. If you are not familiar with these types of maps, familiarize yourself with the map that your instructor gave you: what is shown? What do the different colors or patterns mean (look at the legend)? Look at different regions on the map -- how does the theme change from place to place? Start by simply describing what you see, e.g., by stating what environmental problems region X confronts, and which problems region Y has to battle. Then try to make sense of it: does the map (or other accompanying maps that you have at hand or things you know about this region) give you any clues as to why you would find this particular environmental problem there? You may think of industrial or agricultural activities, population numbers, size of cities, climate, biogeography, etc. For any one region you look at, do you think -- based on the relationships between environmental problems and possible causes that you just determined -- that population is an important driving force behind the environmental problem? And how about wealth and poverty -- do you think that the level of socioeconomic well-being is a driving force behind environmental impacts? In the regions that you looked at, which of these seems to be the most important?

Discuss all these questions with your neighbor or group and take notes of what you and your classmates think of these questions.

Student Worksheet 1.5

Activity 1.5 The World is Your Classroom

Let's move furniture! Or at least, let's find enough space to create some kind of a representation of the world (this could be anything from a big map of the world put flat on a table, to using chairs or counting off floor tiles to represent the land area of the continents -- whatever works in your classroom). If you have enough time, figure out yourselves how many chairs you need per continent (it's a function of [1] the percentage of each continent's land area of the total land area of the earth, and [2] the number of chairs you have available); or else your instructor will help you figure it out.

Now let's see how population, wealth, energy usage, CO_2 emissions etc. are distributed across the world. Depending on how many students or items there are, and what the actual share in each of these variables is per continent (your instructor has that information), you will assign the appropriate number of students or items to each group of chairs/floor tiles (i.e., your "continents"). Take a moment to realize the differences! For example, the number of people per land area (called *population density*) is much higher in Asia than in Africa; it's also much higher in Europe than in North America. Do this exercise with a few more variables.

Finally, take about 5 minutes to write down your impressions from this activity. What impressed you the most? What was surprising to you? What was new? What do you feel you just learned?

1 Human Driving Forces of Global Change

Answers to Activities

There are no pre-determined answers to the exercises in this Unit, but the following information may be used as a guide to assessing the outcomes of the activities.

Activity 1.1 Starter Activity

This activity is intended as a guide for initiating class discussion. The discussions will vary based on the questions the instructor chooses to focus on, as well as on students' enthusiasm and familiarity with the topics.

If the instructor chooses to do the extension of this activity, students will prepare a diary of their progress in changing one thing in their daily life that may reduce their energy usage. Be certain that students have provided a clear and concise account of their daily progress, and that they have indicated how this change has affected their life, as well as their resource/energy consumption.

Activity 1.2 Taking Good Notes

Use *Supporting Material 1.2* and your own experience and expectations to determine whether students are taking good notes.

Activity 1.3 What Do You Know About Your World?

There are no correct or false perceptions of the world, only different ones. As you listen to students' discussions with each other, ensure a non-judgmental environment. Such an environment will allow students to explore their own perspectives freely, and you will gain valuable insight into the degree of knowledge your class brings to this module. Depending on your choice of student assessment method, this activity could be adopted so as to function as a baseline from which to judge student learning made throughout the module.

Activity 1.4 Environmental Problems the World Over

The exact results of this exercise differ of course with the maps students work with. Use the guiding questions on *Student Worksheet 1.4* to lead students through the steps of reading maps (basic understanding of map components; description of mapped theme by type and region, searching for explanatory hints; interpretation).

Activity 1.5 The World is Your Classroom

In the impressionistic notes students take after the activity, their degree of surprise and what they learned depends on their previous knowledge of the distribution of population and wealth across the globe. This is another valuable exercise for revealing the state of your class's knowledge, and thus for indicating where you might have to focus special attention during the teaching of this module.

In addition to making the obvious points about population density and share of world wealth, energy, and/or pollution, instructors can also point out the differences between crude population density (population per km^2) and physiological density (population per km^2 of arable land). The difference between total and per capita data is aptly demonstrated through this activity. Instructors may also want to bring up the distribution of wealth within each society. In short, there are many possible directions this activity can lead.

2 Population Growth

Background Information

Basic Population Geography Concepts

Having discussed some basic theoretical approaches to the study of the "population-environment nexus," let's now look at some basic concepts in population geography studies before we go into the substance of the population-energy relationship. First, let's simply begin with the number of people on planet Earth.

5.7 Billion People

Human population is now measured in the billions -- roughly 5.7 billion in 1996. A billion is 1,000,000,000. 5.7 billion is a five thousand seven hundred millions. Or, spelled out, 5.7x10x10x10x10x10x10x10x10x10, also written as 5.7×10^9. How does one visualize a number like a billion? It helps to compare it to a more familiar number, like a million. We can visualize a million people as, for example, in a huge march on Washington, DC; or 20 full football stadiums; or the population within the Dallas or Detroit city limits. The world's population of 5.7 billion people is the equivalent to 5,700 Dallases (most of these, fortunately or unfortunately, do not consume as much oil or food as the average Texan!).

Let's use another comparison. A deck of 52 playing cards is just over half an inch thick -- call it 50 cards per half inch. A million playing cards would be 10,000 inches, nearly three football fields long, or nearly as high as San Francisco's Transamerica Pyramid building. A billion playing cards, to give us a feeling for its enormity, would stack 158 miles high, well into the ionosphere, or about the distance from New York City to Albany, NY or Chicago to Madison, Wisconsin. And 5.7 billion playing cards, stacked on top of each other -- not laid end-to-end -- would stretch about 900 miles, or the distance from New York City to Atlanta, Georgia.

Exponential Growth of Population

This history of human population growth is a remarkable one. For thousands of years, humans grew very slowly in numbers. This had a lot to do with people's still limited ability to extract the resources of the land and thus to maintain larger populations. With the Scientific Revolution, this picture changed dramatically. For reasons discussed in more detail below, human population began to grow at a rate much greater than anything seen before. In fact, this was the beginning of what some call the population explosion. Technically, this type of growth is described as **exponential growth**.

Exponential growth occurs when things grow as a percentage of their base amount, like a bank account which continually earns interest not just on the principle but on the previous months' interest payments. Things that grow exponentially exhibit the property of doubling in size every X number of years. For instance, at 4% growth, a population will double from 1,000 to 2,000 in 18 years. It will double again, this time from 2,000 to 4,000, in another 18 years, and from 4,000 to 8,000 in the next 18 years. In this example, the duration of 18 years is called the **doubling time**. The *relative* increase over time is the same (population doubles every 18 years), but the *absolute* increase is twice that of its previous increase; in short it is *exploding*.

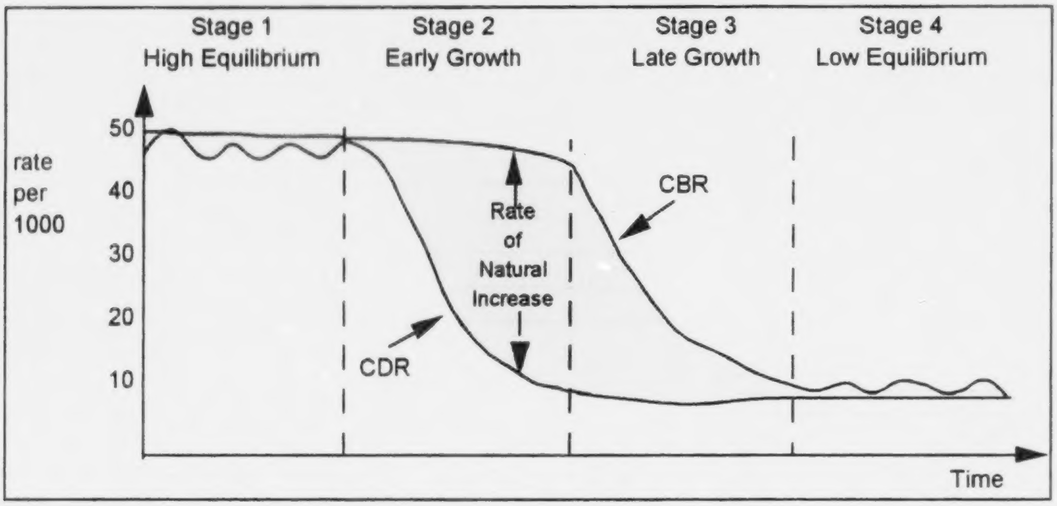
Although specific phenomena have at times increased and decreased the world population's growth rate (e.g., the improvement of hygiene, progress in medicine, economic development, or epidemics, wars, and hunger, respectively), human population growth has in general been exponential and then some, with the absolute growth rate increasing *and* the doubling time concurrently decreasing over time. It took more than a thousand years to double the population from 250 million to 500 million, but it took only about a hundred years to double from 1 billion to 2 billion (1800-1900). From 1900 onward, it took just 50 years to double the world's population from 2 to 4 billion.

The Demographic Transition Theory

The **demographic transition theory** is an important if not unanimously accepted theory in demographic studies. It describes the process of change from high birth rates and death rates to low birth and death rates as related to economic development (Daugherty and Kammeyer 1995). The theory can be illustrated in a diagram (Figure 7) showing two curves over time -- one for **crude birth rate** (CBR) and one for **crude death rate** (CDR). Crude birth and death rates are measured as the number of live births per 1000 population and the number of deaths per 1000 population. When both are high, they offset each other and the population is in **equilibrium**: even though some people are dying and others are being born, the total stays relatively stable. By the end of the demographic transition, both birth and death rates are low, which means they are again at equilibrium. In between, however, is a period where the CBR and CDR are out of equilibrium. When the CBR curve is above the CDR curve on Figure 7, the vertical gap represents the excess of births over deaths: the differential is the percentage rate of natural increase of the population (not including in/out migration). In other words, this period is a time of rapid population growth. For instance, if CBR=40 per 1,000 and CDR=25 per 1,000, then the rate of natural increase is 15 per 1,000, or 1.5 per 100, that is, 1.5 percent. Thus, the adjustment period between the high and low equilibria explains why population growth in the developed countries increased exponentially, and also why it eventually stopped again. What set off this period of exponential growth in European countries was the Scientific Revolution.

The demographic transition theory holds that in the stage before the Scientific Revolution, life expectancy was low owing to poor nutrition, poor medical care, unreliable food supply, and poor sanitation. The high death rate is matched by a high birth rate, keeping the growth rate fairly low. During the second stage, as innovations began to occur, the death rate dropped because of medical advances, better nutrition, a more reliable food supply, better sanitation, etc. The birth rate, however, remained high. During the third stage, the birth rate falls for a number of reasons. In an increasingly urban industrial economy, children become a "cost" rather than a source of cheap labor as in a farming economy. Education becomes more important, so more people stay in school longer, marry later, and have fewer children as a result. Societies begin to develop social security systems to care for the elderly, and improved prenatal and postnatal medical care brings down the infant mortality rate. Both trends lessen the need for parents to have lots of children so that at least some will be there to care for them when they are old. Cultural attitudes toward contraception also change; people integrate the medical and technological advances of society into their personal lives and choices. For all of these reasons, the birth rates eventually fall, while the death rate begins to flatten out and life expectancies level off in the neighborhood of 70 to 80 years. Finally, in the fourth stage of the demographic transition, the death rate and birth rate are once again stable, but both are at a considerably lower level than they were before the Scientific Revolution. Some of the advanced industrial economies of Europe, as well as the US, Japan, and a few other wealthy countries where a very low population growth has been achieved, are frequently given as examples of societies at this stage.

Figure 7: The Demographic Transition



The demographic transition theory was developed based on the historical experience of western industrial countries in Europe and North America. There is some disagreement about its transferability to contemporary less developed countries. Among the arguments brought forth against an easy transfer of the theory to the current situation in less developed nations are the following:

- While Europe took several centuries to go through the transition, the Third World is experiencing it much more rapidly; for example, Sri Lanka's death rate dropped from 48 to 28 in just two years.
- Europe experienced rapid economic growth as it went through the transition, an experience not mirrored in most of the Third World.
- European countries had a population "safety valve," namely colonialism, through which the surplus European population was able to emigrate to colonized nations. Today's less developed countries do not have such a safety valve.
- Finally, most of the Third World entered the transition with a much higher population density than that found in early modern Europe.

Thus, there are no guarantees that the demographic transition will happen in the same way or to the same extent in the Third World as it did in Europe and other industrialized regions.

There is also the question of whether the development of an urban-industrialized society is really a prerequisite for lowering crude birth rates. Countries such as Mauritius, Sri Lanka, St. Vincent, Indonesia, and China have achieved low birth rates despite remaining predominantly poor and rural. In these cases, family planning programs -- both voluntary and coercive -- have lead to couples having fewer children.[15] In summary, the demographic transition theory might in any specific case not fully or perfectly describe the path to lower population growth.

The Hidden Momentum of Population

Given that some family planning programs succeed in the sense that they reduce the number of children per family, one could argue for more of these programs as the quickest tool to decrease population growth. If families are allowed to have only two children (roughly equivalent to the "replacement level" because two children eventually replace the two parents) then population should remain stable -- right? It turns out that this argument, stated as such, is too simple and ultimately not true. Why?

Even if all women of child-bearing age (15-49) decided at once to have only two children (on average), i.e., if the **fertility rate** dropped to the replacement level overnight, the population would continue to grow at least another 50% before it stabilized. This seemingly paradoxical phenomenon is called the **hidden momentum of population**. To understand the hidden momentum and the replacement level argument, one needs to compare the number of babies to the number of people dying, rather than comparing -- as many do -- the number of babies to the number of parents. Population growth approaches zero only when the number of births is completely offset by the number of deaths. If a nation's population has been growing rapidly for decades, it will be disproportionately made up of young people that are either in, or approaching, child-bearing age. On the other hand, the proportion of elderly people in such a country will be relatively small. Thus, even though young parents may have only two children each, there would still be more babies being born than old people dying. As a result, the population will continue to grow. Not until the population has had some time to age will the birth and death rates reach equilibrium. And only if the number of births were reduced to the number of people dying in any year would there be an immediate stop to population growth (i.e., zero population growth).

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[15] A discussion of such family planning programs -- their structure, methods, degree of coercion *versus* voluntariness, resulting social impacts, i.e., their "success" and acceptability -- goes beyond the scope of this part of the module. You may consult the Committee on Women, Population, and the Environment's publication *Political Environments*, which features this controversial issue repeatedly (see *Appendix A* for more information).

The hidden momentum phenomenon is illustrated in Activity 2.7 through the introduction of a very important tool in demographics -- the age-sex distribution, more commonly known as the "population pyramid." The implications of the hidden momentum of population are enormous because this phenomenon causes a major delay in changing the course of the human-environment system. Meadows et al. (1992) use the analogy of a car trying to stop at a red light. If the traffic light is functioning, the visibility is clear, the driver is sober and steps on the brake pedal, the road is dry, the brakes are good, and the car is not speeding -- if all of those elements are in place--the driver should be able to bring the car to a halt before careening through the intersection. If any of those elements is missing -- and especially if several are missing -- there is a real danger of overshooting the stopping line. Applying this analogy to the hidden momentum of population growth, we could say that our population growth brakes are not functioning well, and hence that the world's population may come to a screeching halt only after it has overshot some of its resource limits, its carrying capacity. We thus may ask:

- What constitutes a valid yellow or red traffic light signaling that we are close to exceeding, or have already exceeded, the carrying capacity, and how well can we see it? (See also the discussion of population densities below, and the earlier discussion of the "mediating" school of thought.) Note also that with technological change like the higher-yielding hybrids of corn, wheat, and rice developed in the Green Revolution, the location of the traffic light itself is a moving target that gets farther away all the time.
- Who is driving the world's car, and when will we step on the brakes? According to those who adopt the Individualist perspective (see Figure 5 above), there are 5.7 billion drivers, not one. From the Collectivist perspective, there are various groups (capitalists, multinational corporations, advertisers, the dominant male sex, or a dominant ethnic group) behind the wheel.
- Where are the drivers trying to go, and when do they want to get there?

Population Density

In a world without exchange between regions, the carrying capacity concept would have everything to do with another important demographic concept -- population density. Geographers use the term **crude population density** to refer to the population per square mile (or km^2) of land. It is in no way a reliable signal of "overpopulation," however, because it does not take into account urbanization, climate, technology, trade, or any other factors. A somewhat better measure is provided by the **physiological density**, which is the number of people per km^2

of arable (cultivable) land. Egypt, Libya, and Algeria for instance, have low crude densities because of their large areas, but much higher physiological densities because most of the land is desert. However, even physiological density is not a reliable measure of whether a country has exceeded its carrying capacity. Are industrial city-states like Singapore, with very little farmland, overpopulated? Singapore is able to import most of its food needs using money earned from its industrial exports. Also, it should be obvious that a hectare of intensive triple-cropped rice paddies can support many more people than a hectare of Canadian wheat. Fertilizer use and whether the grain is eaten directly or fed to livestock also affects the number of people who can be fed. The important point here is that population density should never be used alone as an effective signal that a population is approaching its carrying capacity.

And What Again Does Population Have to Do with Energy?

Unit 1 of this module provided an overview of how population growth fits into the debate on environmental degradation -- or environmental changes more generally. As this unit has shown, population dynamics are highly complicated in and of themselves. Furthermore, the role that population plays in global environmental change is complex, incompletely understood, and likely to vary regionally. We have also seen that depending on the value-colored, theoretical approaches researchers employ, the answers to what importance population plays in environmental transformation, and how exactly the two are causally linked, vary significantly.

Now we are about to bring in the other major component of this module: energy. Isn't it complicated enough? -- you might ask. Well, yes, it is complicated and yet -- to discuss either the population issue or the energy consumption issue in a sophisticated way, we have to understand the *linkages* between the two. In fact, you will more often find this linkage discussed as the truly problematic (and also most interesting) issue in environmental debates and scientific literature rather than the "purist" argument that says it is *either* one *or* the other that we need to worry about.

In a general sense, you already touched upon the linkage between population and energy earlier in this module when you learned about the I = PAT formula. I = PAT, as you recall, says that environmental changes occur as the combined (or multiplicative) result of population changes, affluence, and technology. Let's focus on the latter two components for a minute. Affluence and technology are expressions of a country's economic and developmental status. Affluence says something about the value of the goods and services that a country produces, which, through consumption or trade, is used to produce its level of socio-economic well-being. Technology, on the other hand, says something about the level of sophistication with which a nation does that: how efficient, how resource-intensive, how clean or environmentally sound are the processes through which a nation achieves its socio-economic well-being? Unit 3 of this module is exactly about these two components, studied through the lens of energy usage.

Energy, one could argue, is simply one example of a resource that we employ in producing economic growth and well-being (indicators of affluence), and we use it through particular technologies. Both the amount of energy we use, and the technology with which we use it, determine a large part of the environmental impact (population being the other). In this sense, we could have discussed copper, uranium, timber, or bauxite (the raw material for aluminum) just as well. Yet, besides energy being quantitatively much more important than any other resource we use, there is one big advantage to looking at energy instead of all the other kinds of resources, and that is its obvious linkage to global change, in particular, global climate change.

Whenever we use energy from fossil fuels (as is still most common in the world today), we emit CO_2. This gas, as mentioned in Unit 1, is one of the major greenhouse gases that contribute to global warming. Some of the arguments that connect energy, population, technology, and climate change go something like this: When many of us use even a little fossil fuel, we emit much CO_2 (the population argument). When few of us use much fossil fuel, we still emit much CO_2 (the affluence argument). When many of us use much fossil fuel, we emit many times more CO_2; thus, we need either to use efficient technologies to make the available energy go around and avoid catastrophic environmental impacts such as severe global climate change, or to find alternative energies altogether (the technology argument).

But this is jumping ahead! The next unit looks at energy use in greater detail to ensure that we have a good understanding of the affluence/technology (via energy) part of the I = PAT equation. The concluding section, Unit 4, synthesizes all the pieces of the population/energy/environment relationship.

2

Population Growth

Instructor's Guide to Activities

Goal

The activities associated with Unit 2 consist of several exercises that fall into two sets. The first set of exercises (Activities 2.1 through 2.3) explores the nature of exponential growth and the implications of this kind of growth for global population issues. In the second set of exercises (Activities 2.4 through 2.7), students will learn about population structures (by age and sex) of different types of populations and learn how to interpret and construct population pyramids

Learning Outcomes

After completing the following activities, students should be able to:

- interpret the meaning of a relationship plotted on arithmetic, semi-log, and log-log graphs;
- distinguish between cross-sectional and longitudinal data;
- critically evaluate different ways in which population growth is graphed;
- have an appreciation for how big the world's population is;
- understand the concept, causes, and implications of "exponential growth";
- understand the concept of "doubling time" and its relationship to global population issues;
- understand how to summarize age and sex characteristics of a population in population pyramids;
- understand the causes and implications of the hidden momentum of population growth;
- be familiar with age-specific mortality and fertility rates;
- know what factors cause birth rates and death rates to diverge and return to equilibrium;
- think clearly about the extent to which the demographic transition theory is transferable from the developed countries' experiences to the developing world; and
- appreciate the difficulty of population projections.

Choice of Activities

It is neither necessary nor feasible in most cases to complete all activities in each unit. Select activities that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

2.1 The Growing Years	-- Graphing linear, non-linear, and exponential relationships
2.2 Critters in a Jar	-- Data plotting, basic calculations, and team work
2.3 Doubling Time	-- Basic calculations, short answer questions
2.4 The Shapes of Populations to Come	-- Interpretation of semi-log and log-log graphs; short answer questions

2.5 "Be Fruitful and Multiply!" -- Quick and basic calculations of world population growth

2.6 The Demographic Transition Over Time and Space -- Longitudinal and cross-sectional analysis of population data, data plotting, and short answer questions

2.7 Explaining the Hidden Momentum of Population -- Interpretation of population pyramids, data plotting, and short answer questions

Suggested Readings

The following readings accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

- Unit 2, *Background Information*: Population growth (provided)
  The background information to Unit 2 (all students should read)
- Bongaarts, John. 1994. Can the growing human population feed itself? *Scientific American* March: 36-42.
- *EPA Journal*. 1990. Special issue on population and the environment. 16, 4 (July/August); select one or several readings.
- Pulliam, H.R. and H.H. Haddad. 1994. Human population growth and the carrying capacity concept. *Bulletin of the Ecological Society of America* September: 141-157.

Activity 2.1 The Growing Years

Goals

In this activity, students become familiar with linear, nonlinear, and exponential growth and develop skills for making and interpreting graphs of growth.

Skills

- ✔ understanding the concept of growth
- ✔ graphing growth
- ✔ recognizing and distinguishing linear, nonlinear, and exponential relationships
- ✔ working with a partner
- ✔ explaining concepts and tasks to each other and critically discussing questions

Material Requirements

- *Student Worksheet 2.1* (provided)
- pencils

Time Requirements

30 minutes

Tasks

Students read the text and complete the questions on *Student Worksheet 2.1*. This can be done individually or in pairs. When students work in pairs, ask them first to read a portion of the text until they get to the first question. They should stop there and discuss with their neighbor how each would go about answering that question. If one has difficulty understanding a concept or task, the other should try to explain it. Both proceed individually if there is a graph to draw or a chart to fill in; when they are finished, they exchange their worksheets and compare their results. If there are questions to answer, they should discuss their answers with each other first, and after they come to a satisfactory answer, write them down individually.

Instructors assist only when students can't help each other understanding the concepts and tasks.

Activity 2.2 Critters in a Jar

Goals

This activity illustrates that a constant doubling time of population is a characteristic of exponential growth and introduces students to semi-log graphs for portraying exponential growth.

Skills

✔ plotting data in arithmetic and semi-log graphs
✔ observing a process and recording it in a written narrative
✔ calculating percentages
✔ extrapolating observations to the future
✔ analytical thinking

Material Requirements

- *Student Worksheet 2.2* (provided)
- watch showing seconds or timer (one per team)
- 64 pennies or tokens (per team)
- note paper
- pencils

Time Requirements

20 minutes

Tasks

Students team up in groups of 3 or 4. Each group should have at least one copy of the "Critters in a Jar" graph (*Supporting Material 2.2*), a watch or timer that shows seconds, 64 coins or tokens, *Student Worksheet 2.2*, pencils, and a note pad. (You may want to hand out a copy of the graph to each student on which they can mark with colored pencils the numbers of critters added each minute.)

The team reads through the introductory part of Activity 2.2. They devise roles for each team member according to the tasks the exercise calls for (a time taker, someone adding "critters" to the jar, someone tabulating and plotting the observed results after each minute, and a reporter).

After the jar has been filled with critters, the team should go over the tabulation, the plot, and the observations made during the process, and see if they need to correct or add anything. Then they discuss together and fill in the answers to the questions following.

Students then read the next section on semi-log graphs and plot the tabulated data from the experiment again on the provided semi-log graph paper. The team should discuss the last question of Activity 2.2 and present their answer to the class. If students have difficulty imagining exponential curves with different growth rates, the instructor may demonstrate an example on the black board.

Activity 2.3 Doubling Time

Goals

Students learn how to apply percentage growth rates to the calculation of population doubling time and will recognize the limitations of the doubling time concept.

Skills

- ✔ applying previously introduced concepts (exponential growth, growth rate, etc.) to human populations
- ✔ applying an abstract concept (doubling time) to a real example (Bangladesh)
- ✔ analytical thinking

Material Requirements

- *Student Worksheet 2.3* (provided)
- calculator

Time Requirements

15 minutes

Tasks

This exercise may be done individually or in pairs. Students read the introductory notes to Activity 2.3 on *Student Worksheet 2.3*. Before they do the "calculator-punching" exercise, give students a moment to reflect whether they understood the concept of doubling time. Allow a short period for asking questions or explaining to each other what it means.

Students then work (together) through the calculating exercise, filling in at least the first ten lines provided. Then they discuss with each other and write down the answers to the last two questions of Activity 2.3. The answers to each question should be shortly reported by one in the pair to the class, and difficulties or answers should be discussed with the whole class.

If you encounter science- or math-phobia in the students, see the *Notes on Active Pedagogy* for helpful suggestions.

Activity 2.4 The Shapes of Populations to Come

Goals

The purpose of this activity is for students to become critical consumers of graphical information and to recognize the strengths and weaknesses of different kinds of graphs.

Skills

✔ understanding and interpreting semi-log and log-log graphs of population growth
✔ analytical thinking

Material Requirements

- *Student Worksheet 2.4* (provided)
- a color marker

Time Requirements

20 minutes

Tasks

This exercise can again be done individually or in pairs during the class period or as homework by students individually. It is useful if students have already done some reading or heard in class about how technological innovation relates to population growth. The worksheet contains all the necessary instructions for the student to complete the activity; however, the instructor should be prepared to answer questions from students about arithmetic and logarithmic scales and interpreting graphs of population data graphed on these scales.

If this activity is done in class, include additional time in the estimate above for discussion among students on each question.

Activity 2.5 "Be Fruitful and Multiply!"

Goals

In this exercise, students acquire a better sense of the rate of world population growth.

Skills

✔ applying simple math to calculating population growth
✔ problem solving
✔ analytical thinking

Material Requirements

- *Student Worksheet 2.5* (provided)
- calculator

Time Requirements

5 minutes

Tasks

Students calculate the annual, daily, and hourly addition of people to the world's population, working individually, then comparing results with their neighbors. If they have difficulty solving this math problem, ask them to explain to each other how to go about solving it. The instructor should check after a few minutes that all students got the correct answer. It is also useful to frame the answers in terms of "Every *year*, the world population grows roughly by the equivalent of the population of Germany/Mexico," or "Every *day* we add the equivalent of a Corsica/Iceland/Brunei/the Bahamas to the world," or "Every *hour* the world population grows by the size of a [use a nearby town your students will know with a population of about 9,600]."

Activity 2.6 The Demographic Transition over Time and Space

Goals

The purpose of this activity is to offer a critical perspective on the demographic transition theory. This activity is more lengthy than previous ones and is divided into two parts. The first is a longitudinal analysis that demonstrates how the demographic transition does not occur in the same way or at the same rate in the developed and developing world. The second part contains a cross-sectional analysis in which students investigate the variation and flexibility within the demographic transition model. Specifically, to what extent have any low-income countries managed to achieve low birth rates without economic development, and to what extent have any high-income countries failed to achieve low birth rates despite economic development? These two analyses reinforce a student's overall understanding of the demographic transition theory through graphing it and identifying the stages.

Skills

✔ longitudinal and cross-sectional analysis of population data
✔ delineation of stages of the demographic transition theory based on empirical data
✔ critical assessment of the applicability of the theory to different nations
✔ data plotting and interpreting
✔ data sampling

Material Requirements

- *Student Worksheet 2.6* (provided)
- (see also Data Sources needed below)

Time Requirements

About 30 minutes for each part. Half of the class might do Part 1 and half Part 2, either in class or as homework. Allocate an additional 20 minutes in class for discussion and for students who did one part to teach their part to the other half of the class.

Suggested Readings

The following readings are suggested specifically for Activity 2.6. The readings are generally very short, but you may choose those that best suit your class and students' abilities.

- Bulatao, R.A. 1992. Family planning: The unfinished revolution. *Finance & Development.* December: 5-8. Reprinted in *Third World 94/95,* R.J. Griffiths, ed., 198-201. Guilford, CT: Dushkin Publishing Group.
- Barr, C. 1992. Female empowerment leads to fewer births. *Christian Science Monitor.* July 8: 14. Reprinted in *Third World 94/95,* R.J. Griffiths, ed., 228-230. Guilford, CT: Dushkin Publishing Group.

Data References Needed

One or more of the volumes listed below provide data for updating the activities or for alternative countries that students would like to work on:

- *World population data sheet.* Recent edition. Washington, DC: Population Reference Bureau.
- The World Bank. Latest ed. *World development report.* Oxford: Oxford University Press.
- Any other source of demographic and economic data for countries (e.g., PC-Globe).

Tasks

This longer activity explores the strengths and weaknesses of the demographic transition theory both as an explanation for the population explosion and as a force that might naturally defuse it. Students should have already learned the basic demographic transition theory from readings or class.

As an alternative, this activity can be used as a homework assignment. If the instructor chooses to use it as homework, students should consult additional sources (encyclopedias, regional geography books, maps) to formulate well-documented and thorough responses to the written questions.

Part 1: Stages of the Demographic Transition: Longitudinal Analysis and Comparison of Developed and Developing Countries' Experiences

The first question of the demographic transition activity allows students to recall the readings and to understand the difference between longitudinal and cross-sectional studies. The rest of Activity 2.6 explores the differences between the demographic experiences of a developed and a developing country: England and India. You may choose to use different countries, particularly if you decided to let students become familiar with one particular country that they follow throughout this module.

Have students plot India's CBR and CDR data onto the same graph on which they plot data for England. You may have an overhead of the plotted longitudinal data ready so that you can divide the graph into the stages of the demographic transition together with the class. Ask students to explain where they would like to see the division between two stages drawn, and why. Allow them to discuss this with each other.

Part 2: Comparison of Developed and Developing Countries' Demographic Experiences

For the cross-sectional part of the exercise, you need to supply students with population data from a data source such as the *World population data sheets* or the World Banks' *World development report.*

You may have students work in pairs on this part of the activity and have them help each other understand concepts like crude birth rate, crude death rate, sampling, curve fitting, etc. Assist only when students are stuck.

After both parts of the activity have been completed, bring the class together and discuss what the students learned in the activity. Ask students to consider the utility and the limitations of the demographic transition, and end the discussion by attempting to bring some closure to the debate.

Activity 2.7 Explaining the Hidden Momentum of Population: A "What-if" Scenario for Mexico

Goals

Students will understand the cause and effects of demographic momentum or "the hidden momentum of population growth." Students first learn what a population pyramid shows about the age-sex structure of a population, and then apply that knowledge to explaining the delay in the cessation of population growth.

Skills

✔ analytical thinking
✔ interpretation of population pyramids

Material Requirements

- *Student Worksheet 2.7* (provided)
- *Supporting Material 2.7* (provided)

Time Requirements

1 class period (50-60 minutes)

Suggested Readings

The following readings are specific to Activity 2.7. You may use these as background information for yourself or select some as additional reading assignments for the students.

- Merrick, Thomas W. et al. 1986. World population in transition. *Population Bulletin* 41, 2. Washington, DC: Population Reference Bureau.
- Moffett , G.D., III. 1992. World population. *Christian Science Monitor*. July 8: 9-16. Reprinted in *Third World 94/95*, R.J. Griffiths, ed., 182-184. Guilford, CT: Dushkin Publishing Group.
- Haub, Carl. 1987. Understanding population projections. *Population Bulletin* 42, 4. Washington, DC: Population Reference Bureau.

Tasks

In this exercise, students will learn about population structures (by age and sex) and population dynamics by interpreting population pyramids. Using Mexico as an example, students will demonstrate the "hidden momentum of population," whereby population continues to grow for many years after the population adopts a "replacement level" fertility rate. When population does eventually stabilize, after a long delay, it is at a much higher absolute number of people.

Part 1: Population Pyramids

The first part of this activity works well for pairs of students. Allow them 5 minutes or so to familiarize themselves with population pyramids. Ask them to help each other understand what this type of graphic representation of population data shows. To ease them into understanding population pyramids, they are asked to interpret pre-drawn pyramids.

Part 2: Hidden Momentum

In this part of the activity, students will first read a conceptual explanation of demographic momentum. Then, through interpretation of pre-made graphs, they will see how it is possible for a population to continue growing long after parents in a country have begun averaging only two children each. This scenario will be compared to a business-as-usual scenario with no change in fertility rates. Mexico will again be used as the example.

Part 3: Implications of the Hidden Momentum of Population

In this final part of Activity 2.7, students are asked to tie together concepts and theories they have learned throughout the activities in Unit 2. The questions can be treated as writing exercises or as prompts for in-class discussion. Students are also asked to recall and apply the various approaches to the population-environment debate discussed in the *Background Information* of Unit 1 and take a position. If you decide to use the class-debate format, or simply to provoke your students to think critically, see the *Notes on Active Pedagogy* for useful information on how to teach controversial issues.

2 Population Growth

Student Worksheet 2.1

Human populations grow exponentially. What exactly do we mean by this? Why does it happen? How can exponential growth be depicted in a figure or graph? What are the implications of exponential growth? And why should we be concerned about it? In the following activities, we work toward some answers to these questions.

Activity 2.1 The Growing Years

First, let's think about what it means for something to grow. "To grow" is to increase in size by assimilating material into a living organism or by adding or accreting more material to the original mass of some entity (e.g., world population). Growth takes place in time, so we can describe the amount of growth that takes place as a *growth rate*, or an increment of growth which takes place during a specified period of time. Growth over time can be depicted graphically by plotting the magnitude or size of whatever is growing against time on two axes of a graph.

When we try to think about the size of the world's population (about 5.7 billion in mid-1995) and then try to imagine it growing even larger, it is hard for us to grasp such huge numbers. So let's start by examining the concept of growth with something very familiar. Instead of looking at the growth in size of an entity composed of many organisms (like world population) we'll look at the growth of a single organism -- your own body's height and how your height has grown over time.

Graphing Growth -- an Introduction

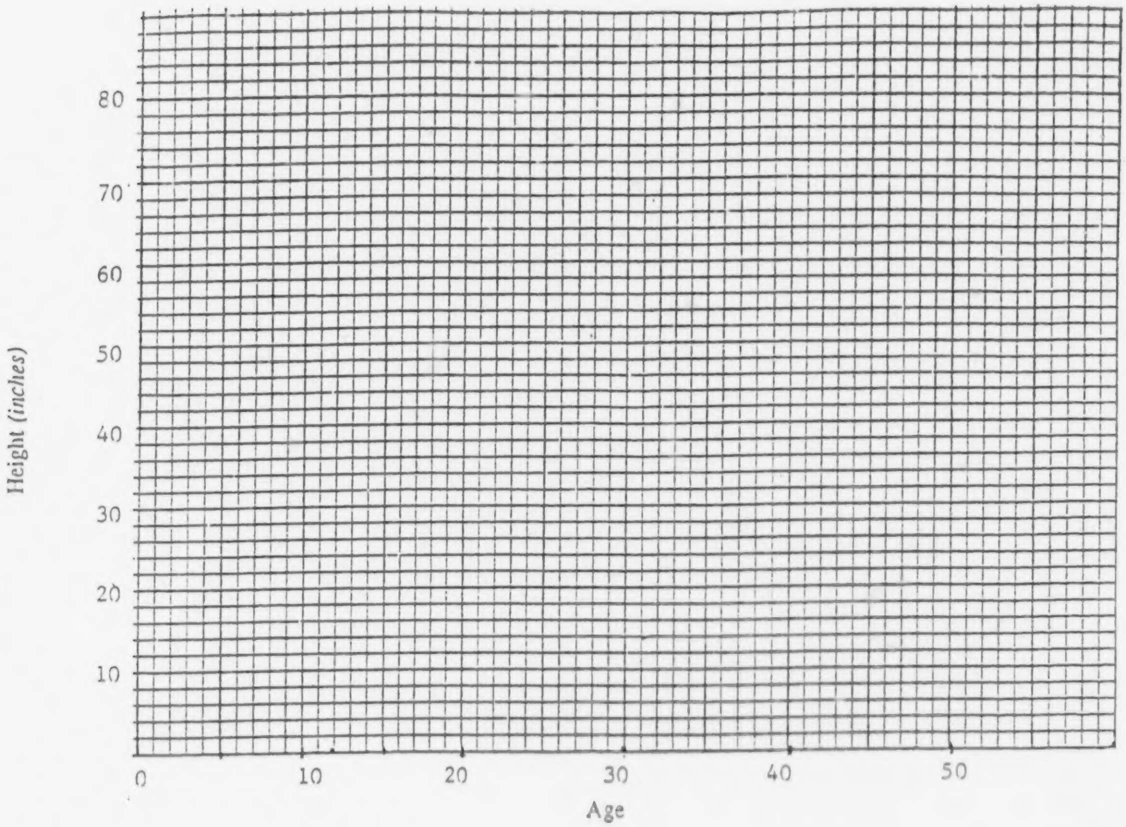
In this activity you will construct a rough graph of your own growth (change in height) -- and expected growth -- from the day you were born (age 0) to your projected height at age 40. To do this you'll need to make some rough (but reasonable) guesses of about how tall you were (or will be) at different points in time: as a newborn, at 6 months, 1 year, 2 years, 5 years, 10 years, and so on.

A. Fill in the table below with your height estimates, then plot the data on the graph beneath the table and smoothly connect each data point with a line.

Table 3: Age and Height Estimates

Age (years)	0	6 mo	1	2	5	10	15	20	25	30	35	40
Height (inches)												

Figure 8: A Graph of My Growth



B. Is it possible to draw a single straight line through all 12 of the data points? ______________

C. Some portions of the line you have drawn are more vertical and some are more horizontal. What do these portions of the graph reveal about your rate of growth at these points in time?

The graph you have just constructed illustrates a growth process that is characterized by varying growth rates at different points in time. Your height increased in spurts during some periods of time, increased more gradually during others, and leveled off in growth during some years. In fact, as you eventually enter into your golden years, you might even find that your height begins to decrease a bit (or experience "negative" growth).

D. Which segments of the graph represent the fastest growthrates?________________________

E. Which represent the slowest growth rates? ________________________

F. If you extend the graph into your future at age 80, what will the growth curve probably look like? ________________________

G. Propose some explanations for the varying shapes of the different segments of your height growth curve over time. ________________________

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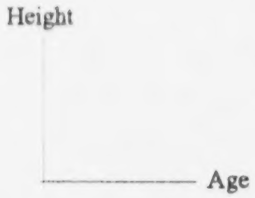
Linear and Nonlinear Changes

H. If babies, children, teens, adults, and the elderly all grew at exactly the same rate for each increment of time throughout a human life cycle (e.g., 2 inches every year), describe in words how the graph would look and how it would differ from the one you just drew. Make a small sketch of what it would look like:



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In humans, a constant growth rate of 2 inches per year is not realistic. However, if we *assume* such a rate, we can easily describe in words the relationship between age and height for a constant growth rate of 2 inches per year:

In words: "Your height after a specified number of years (age) is equal to your initial 'newborn' height (when age = 0), plus 2 inches for each additional year of growth."

In equation form: height *in inches* = initial height *in inches* + (age *in yrs* x 2 *inches per yr*)

In symbols: $y = a + bx$ where
y = height in inches
x = age in years
a = your initial height (in inches) as a newborn
b = the growth rate in inches/years (b = 2 in our example)

I. You've demonstrated in the graph of your own growth that people do *not* grow taller continuously over time at a constant growth rate; hence our equation $y = a + 2x$ does not accurately predict height as a function of age. To illustrate how unrealistic it is, use it to calculate your height (y) at age $x = 60$, if you were born having an initial height of a = 12 inches.

Your answer: _________ inches = _________ feet!! (Note: 1 foot = 12 inches)

We say that growth is *linear* when the change in magnitude each year is directly proportional to the change in time, and we describe such a relationship between time and growth as a **linear relationship**. In graphs, you can easily recognize linear relationships between two variables because the plotted data will form a straight line. As in the graph you produced, the actual growth of a baby to adulthood cannot be depicted with a perfectly straight line or by a simple linear equation. Hence we call this relationship between age and height a **nonlinear relationship**. The growth rate varies over time, making it more difficult to predict future growth either graphically or by using an equation.

The same cautions apply when we try to project future growth in world population. Determining *the causes* for different growth rates of the world's population at different times in history is even more problematic because of all of the variables that are involved. Later in this module we speculate on some possible causes of changing rates of world population growth, but first we need to understand how a population grows and what a graph of population growth looks like.

Exponential Growth

Some things grow, not by adding the same amount of growth over each increment of time arithmetically, but by adding an amount of growth that is based on *a percentage* of the entity's magnitude at each point in time. This type of growth is called **exponential growth**, i.e., anything that grows by a percentage of its starting amount grows exponentially. Imagine that you have a savings account containing $100. You have a choice of either (a) making your money grow by a growth rate that adds $10.00 per year to your savings, or (b) increasing your savings at a growth rate of 10% a year, compounded annually (i.e., figured out anew each year). Which do you choose? The smart choice is to choose the growth rate that is based on a percentage of the amount. Each year you add 10% of a slightly larger amount. The first year, 10% of $100 is $10, giving you $110. The next year, 10% of $110 is $11 so your new savings become $121. The third year, 10% of $121 is $12.10, giving you $133.10. And so on. After ten years, if you had selected choice (a), you would have accumulated $200 in savings, but if you had chosen option (b) your savings account would be almost $260.

Here's another example. A $100 gift, invested at a child's birth in a bond yielding 10% per year will grow to $127,189.54 in 75 years. Not a bad retirement present to give to your children! You may be wondering why nobody thought of that for you when you were born. Well, it's not too late to give yourself a retirement present ... or is it? If you're 20 years old, and you could find a 10% guaranteed return today, you could still invest the $100, but at age 75 your payoff would only be $18,906. By starting 20 years later, you lose $108,284, i.e., the amount the principal would grow between the 55th and 75th year. This example simply illustrates that exponential growth starts out modestly, picks up steam, and eventually gets amazing. If you could live to 100, you'd have $1,378,061. And if you left it to your grandchildren 200 years after your birth, they'd get $18.99 billion. Now imagine how fast things would grow with a growth rate of 100%! Each year every dollar in your savings account would be "replicated" and you would double your savings from the previous year.

Human populations, like savings accounts, grow exponentially. In 1995 world population was growing at a rate of about 1.5% annually, with less developed countries growing at a rate of about 2.2% and more developed countries growing at a rate of only 0.2%. A 2% population growth rate per year doesn't sound like much, but over a period of 250 years, a human population growing at that rate will multiply its original size 141 times. In the next activity, let's use another simple example with manageable quantities to illustrate and graph how a population grows exponentially.

Student Worksheet 2.2

Activity 2.2 Critters in a Jar

Names of Team Members:

____________________ ____________________

____________________ ____________________

Imagine that the glass jar illustrated in *Supporting Material 2.2* contains a unique and prolific type of organism that has the ability to reproduce and generate two new mature (and ready to mate) organisms every minute. One new male and one new female critter are always produced in each mating session between a critter couple. You are part of a research team that must observe and describe the change in population of these prolific critters for a 2½ minute period. The jar initially contains only one individual and your observations will begin as soon as you introduce its mate.

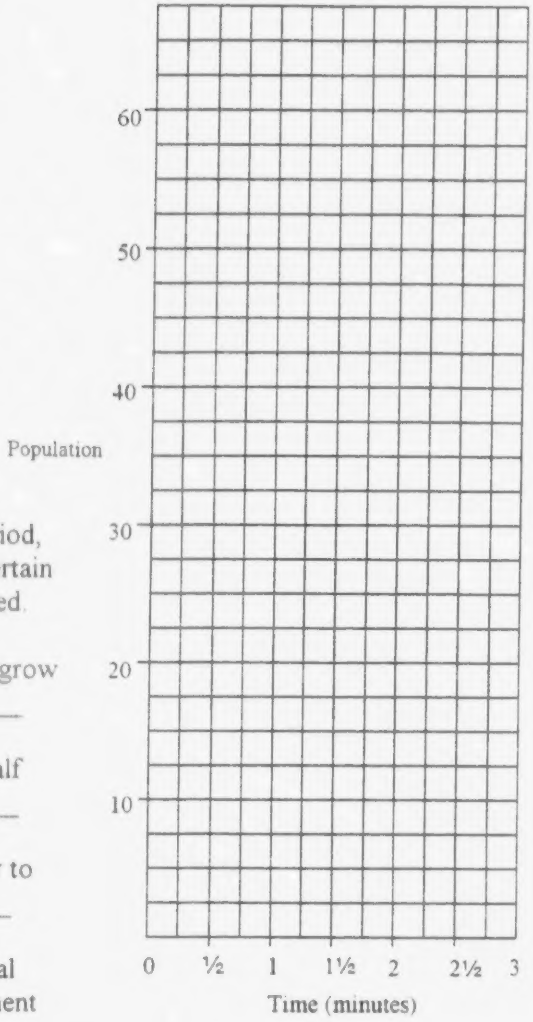
The following tasks should be assigned to members of your team:

1. Time the exercise and announce when each 30-second interval has passed.
2. Add the appropriate number of new critters to the jar during each 30-second time period based on how many "couples" are in the jar at the beginning of the period. Place pennies or tokens, or draw an X in open spots in the jar to represent the new offspring of each couple.
3. Count up the total number of individuals in the jar at the end of each 30-second period.
4. Tabulate the results in the table provided.
5. Plot the data in the table on the graph provided.
6. Be an observer and recorder, describing the whole process from beginning to end and how the appearance of the inside of the jar changes after each passing minute.

Table 4: Population of Critters

Time	Population of Critters in Jar
0	2 (when first mate is introduced)
30 sec	
1 min	
1½ min	
2 min	
2½ min	

Figure 9: Graph of Critter Population



A. At the end of the 2½-minute observation period, discuss the data and observations to make certain every member has all the information collected.

B. By what percentage do the critters in the jar grow each 30-second interval? ____________________

C. How long did it take for the jar to become half full? ____

D. How much longer after this did it take the jar to get completely filled? ____________________

E. The longer something grows at an exponential growth rate, the growth over the next increment of time becomes:

more dramatic less dramatic *(circle one)*

F. If you obtained a larger jar and continued your observation for 2½ more minutes, describe in words what the graph of critter population growth would look like after 5 minutes.

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When values increase so rapidly from exponential growth that you run out of room on your graph, we can use *logarithmic* or *semi-logarithmic* graphs to plot the data. The two graphs you've already constructed were plotted on graph paper having an arithmetic scale, which shows equal amounts of change along each axis. This means that the distance between 1 and 2 along the graph's axis is the same distance that is between 2 and 3, between 3 and 4, and so on. When exponential growth is plotted on such a graph, we quickly run off the scale of the vertical axis.

To remedy this we can use a logarithmic scale on the axes of our graph. A logarithmically scaled graph compresses large numbers in a systematic way. On a log scale, the distance between 1 and 10 is the same as that between 10 and 100, between 100 and 1,000, etc. The distance between 1 and 2 is also the same as between 2 and 4, between 4 and 8, between 8 and 16, etc., which means that a quantity that keeps doubling every so many years will appear to be growing in a straight line if population is graphed on a logarithmic scale and time on an arithmetic scale. (Therefore, be careful not to interpret every straight line as a linear relationship; it depends on the scales of the axes used in the graph!)

We call a graph that has an arithmetic scale along one axis and a logarithmic scale along the other a *semi-log graph*. (Note that scales can be mixed and matched. Your choice depends on the kind of data you are plotting and what you want to show or highlight with your graph.)

G. Plot the same critter population data collected earlier on the semi-log graph below with *time* on the arithmetic axis and *population* on the logarithmic axis. Draw a straight line through the graph that approximates your data points most closely.

An equation of the type $y = a + bx$ can be used to describe this line; therefore we can say that the relationship between time and the logarithmically graphed critter population is linear. In other words, even exponential growth can look like a linear relationship with time when the percent change in magnitude for each increment of time is constant. In our critter population exercise, the growth rate remained constant over each time increment because the number of critters doubled each 30-second interval.

H. If the percent change in population growth had been different from one time interval to the next, how might this alter the appearance of this graph?

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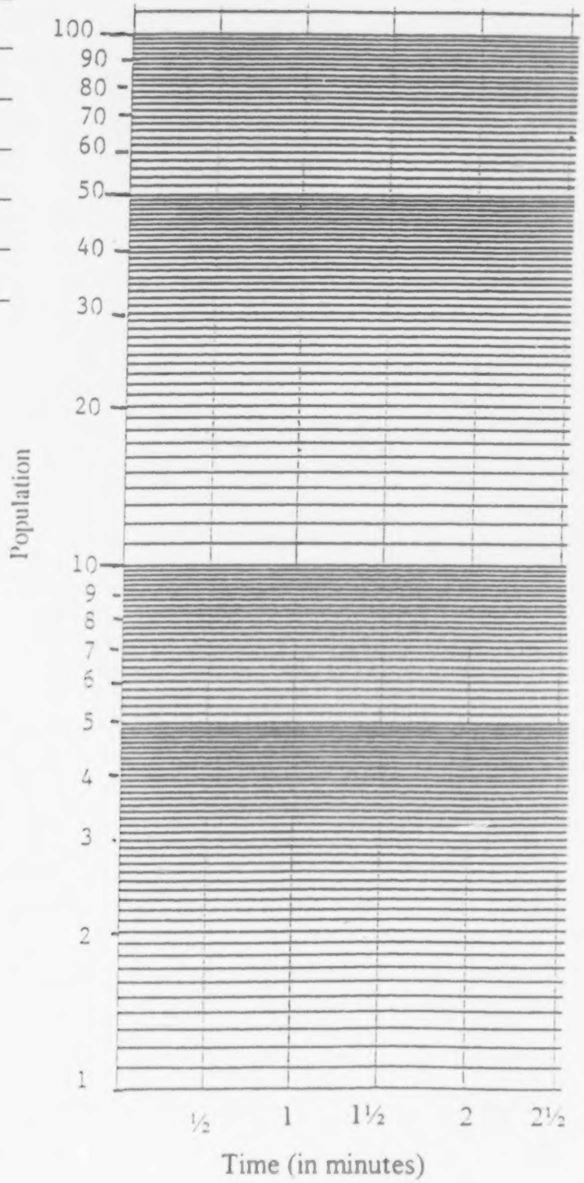
Figure 10: Semi-Log Graph of Critter Population



Student Worksheet 2.3 Name:

Activity 2.3 Doubling Time

If a growth rate continues at exactly the same rate indefinitely, things that grow exponentially will double in size every X units of time (years for something like the world population). This number X is known as the *doubling time*.

A. In our critter exercise, what is the doubling time? __________

Remember that our imaginary population of critters in the jar is exceptionally prolific! We've also made some unrealistic assumptions in our population-in-the-jar exercise, such as not having any of the critters die and having them instantly ready to reproduce as soon as they are born! Real world human populations do not grow as quickly nor could they possibly double in such a short time. However, we can draw the generalization that for populations with a high exponential growth rate (percent change), the doubling time will be shorter, and for populations with a smaller percent change each year, the time for the population to double will be longer.

Now let's look at some real data obtained from the *1995 World Population Data Sheet* put out by the Population Reference Bureau, Inc. In 1995, population growth rates for the fastest growing countries in the world ranged between about 3.5 to 5% annual increase. Oman had a population increase of 4.9%, Gaza 4.6%, the Marshall Islands 4.0%, and Iraq, Syria, Yemen, the Maldives, the Soloman Islands, Comoros, and Côte d'Ivoire between 3.5% and 3.7%. If we select a value of 4% to represent the world's most rapidly growing populations, what is the doubling time (in years) for this growth rate? This is what we'll figure out next.

B. We can determine the doubling time of a population growing at 4% per year through the following "calculator-punching" exercise. Start with a quantity of 1.0 in year 0. Multiply this quantity by 1.04 (i.e., the population in year 0 x 100% (=1.0) + the 4% (.04) population increase). This will give you the population in Year 1. Then multiply the population in Year 1 by 1.04, and so on. Continue filling in the blanks in the table below, carefully watching the growth of the population as seen in the "Amount" column. The year when the quantity you are calculating reaches 2.0 (double the initial value of 1.0) is the year from which you determine the doubling time: how many years passed since year 0? That is the doubling time. Note that there are more blanks below than you really need to fill in to discover the doubling time. The first few calculations are outlined to get you started.

Table 5: Doubling Time of a Population

Year	How to get it	Amount
0		1.0
1	1.04 × 1.0	1.04
2	1.04 × 1.04	1.0816

C. Bangladesh is a country located on the moving shores of the delta of the Ganges and Bhramaputra Rivers in South Asia. About the size of Wisconsin, it had a population of 119 million in 1995. Growing at 2.4% per year, its population would double every 28 years. *If* it maintains its current growth rate, about how many years will it take until the population of Bangladesh surpasses 5.7 billion, the world's current population? Rather than calculating the population for every year, you may want to calculate the population for every 28th year, since you know the population doubles every 28 years.

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D. But wait, you say. That's ridiculous. It'll never happen. Why not?

Student Worksheet 2.4 Name:

Activity 2.4 The Shapes of Populations to Come

No one disputes that the world's population is growing by leaps and bounds. Depending on how you graph it, however, population could appear to be either skyrocketing or slowing down. It could be blazing brand new trails, or simply repeating well-worn historical growth-and stabilization cycles. It all depends on the kind of graph you use to demonstrate this growth.

Interpreting Different Ways of Graphing World Population Growth

The figure on the next page shows the same exact world population growth data plotted in four different ways. The four graphs correspond to the categories below, depending on whether time or population is plotted with an arithmetic or logarithmic scale:

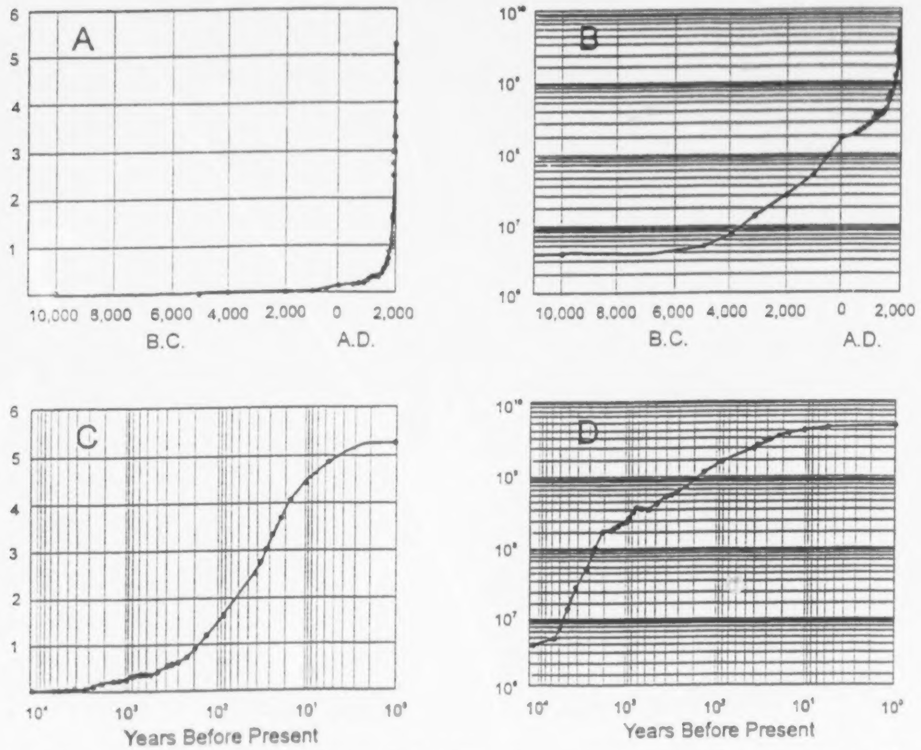
Table 6: Matrix of Ways to Graph Population Growth

	Population (Arithmetic Scale)	**Population (Logarithmic Scale)**
Time (Arithmetic Scale)	Graph A ("J" shape)	Graph B
Time (Logarithmic Scale)	Graph C ("S" shape)	Graph D

As we noted earlier, log scales are generally very useful for two purposes. First, it is quite useful when points on the graph differ by several orders of magnitude (i.e., several powers of 10). For instance, in Graph A, any detail about population growth prior to 2000 BC is invisible to the naked eye. By stretching out the small numbers and compressing the big numbers on a logarithmic scale, Graph B allows us to see some detail in what would otherwise be squashed down on the bottom of the graph.

The second main purpose for log scales is to allow a straight line to be fitted to what would otherwise be a curved data set, as in our re-graphing of the critter population onto a semi-log graph. Note that even though Graphs B, C, and D all have at least one axis that is logarithmically scaled, the data on each of these graphs still cannot be fit with a straight line.

Figure 11: Four Ways to Graph Population Growth



Source: Ausubel, J.H. and Meyer, P.S. 1994. *Human Dimensions Quarterly* 1, 1: 17. Reprinted with permission of CIESIN.

A. Recalling our earlier discussion, what do these curved lines tell us about whether the global population growth rate is it constant or has changed during different periods of history? How did you expect the growth rate to behave?

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We will now look closely at each graph to extract different pieces of information from these four graphical depictions of the same population change data:

B. Graph A shows global population growth with time plotted on arithmetically scaled axes. What does Graph A's "J-curve" shape imply about when the "population explosion" began?

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C. Graph B shows global population growth plotted on a logarithmically scaled axis with time plotted on an arithmetic scale. What population trends are visible in this depiction that are not evident in Graph A? When can population growth first be detected? Is there one pulse (or spurt) of growth (as it appears on Graph A), or two pulses of growth?

D. Graph C shows population plotted on an arithmetic scale and time plotted on a logarithmic scale. The result is a wiggly curve that looks like an "S" and is therefore called an "S-curve." Compare the S-curve in Graph C to the J-curve in Graph A. What does Graph C suggest about past and future population growth? Why do the same data points look so different on Graph C compared with Graph A?

One of the justifications that is given for using a log scale for time, as in Graphs C and D, is that the pace of technological innovation is accelerating. This argument implies that the amount of change in the last 10 years is equivalent to that of the previous 100 years, which is proportional to that of the previous 1,000 years, etc. Hence, the time axis becomes a proxy for a technological change axis.

On Graphs C and D, every vertical line between the 10^2 and 10^3 lines corresponds to a whole century ($10^2 = 100$). Likewise, the vertical lines between 10^3 and 10^4 represent 1,000 year intervals. Using this information to count back in time, on Graph D, indicate with a vertical arrow when the Scientific/Industrial Revolution began (app. 300 years ago) and when the domestication of plants and animals (the Agricultural Revolution) began to spread beyond the Near East (use 7000 BC, although evidence exists for farming in the Nile Valley as long as 18,500 years ago.)

E. How do these two dates in human history seem to relate to population growth rate trends or changes as they are depicted in the log-log Graph D?

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Each of the four graphs (A - D) has strengths and weaknesses in its depiction of the way human population grows and changes over time.

F. When you think you understand and can interpret these different types of graphs and curves, match each of the following critiques with the graph it is most likely referring to:

Critique 1: This graph shows the growth in ancient times fairly accurately, and shows an acceleration of the rate of growth in recent times; however, one does not get a really strong impression of how large the numbers have grown recently.
Graph ______

Critique 2: This graph allows one to see ancient history with as much detail as modern history, and suggests that there have been a series of growth spurts and leveling offs in the past. It is flawed in that it suggests by its shape that growth has petered out in recent times.
Graph ______

Critique 3: This graph suggests that population grew slowly at first, then accelerated, and is now tapering off. It is flawed in that it gives the impression that absolute growth is slowing in recent times.
Graph ______

Critique 4: This graph makes a strong and accurate statement about the absolute increase in the size of human population over time, but it minimizes one's impression of the growth in population of early history and one ends up focusing on recent times.
Graph ______

Student Worksheet 2.5 Name:

Activity 2.5 "Be Fruitful and Multiply!"

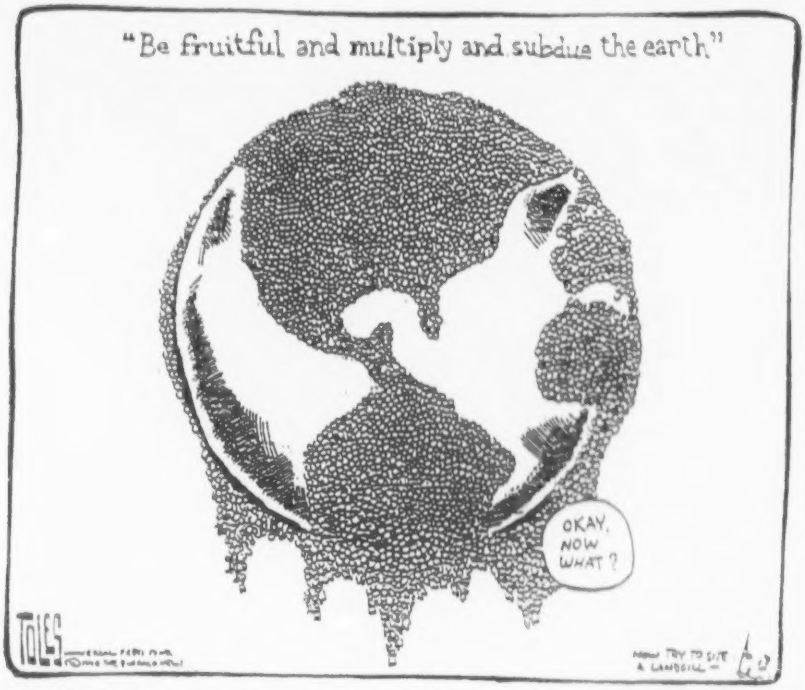
In this exercise, you will make some calculations to get a feel for how large the world's population is and how fast it is changing.

Calculate the annual addition of people to the world population over this upcoming year by multiplying the 1995 population of 5,702,000,000 (5.702 billion) times the annual growth rate of 1.5% (.015). Then, based on this value, calculate the number of people added per day and per hour (round your results to the nearest whole number). You may work together with your neighbor on these calculations, but make sure you know how to get the results yourself.

Annual addition of people = ________________ per year

________________ per day

________________ per hour


"Be fruitful and multiply and subdue the earth"
OKAY, NOW WHAT ?
TOLES
NOW TRY TO SITE A LANDFILL —

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Student Worksheet 2.6 Name:

Activity 2.6 The Demographic Transition over Time and Space

In this activity you will take a critical look at the demographic transition theory, its stages, how one can study it, and how well the theory describes the experience of different countries. You may do it in groups with one-half of the class completing Part 1, and the other half completing Part 2. At the end, be ready to explain what you did to those students who worked on the other part.

Part 1: Longitudinal Analysis and Comparison of Developed and Developing Countries' Demographic Experiences

There are different ways of dividing up the demographic transition into stages: some use a three stage model, with the middle stage sometimes divided into 2a and 2b, while others use four stages. This is largely a matter of semantics. In this activity, we identify four stages:

Stage	Name	Crude Death Rate	Crude Birth Rate
Stage 1	High Stationary	High and fluctuating	High and stable
Stage 2	Early Expanding	Falling markedly	High (perhaps inching downward)
Stage 3	Late Expanding	Leveling off low	Falling markedly
Stage 4	Low Stationary	Low and stable	Low and fluctuating

A. Based on your readings and classroom activities, summarize the factors responsible for (1) the decline of the death rate and (2) the subsequent decline of the birth rate in the demographic transition.

By its very name, the demographic *transition* theory is a dynamic phenomenon over time. The data that support the theory are historical birth and death rates for a single country. Data for a single place over time are known as *longitudinal data*. Before you plot such data below, let us define two terms:

Crude birth rate (CBR) = The number of births in a single year per 1,000 population; or

$$\text{CBR} = \frac{\text{no. of births (year)}}{\text{total population (year)}} \times 1{,}000$$

Crude death rate (CDR) = The number of deaths in a single year per 1,000 population; or

$$\text{CDR} = \frac{\text{no. of deaths (year)}}{\text{total population (year)}} \times 1{,}000$$

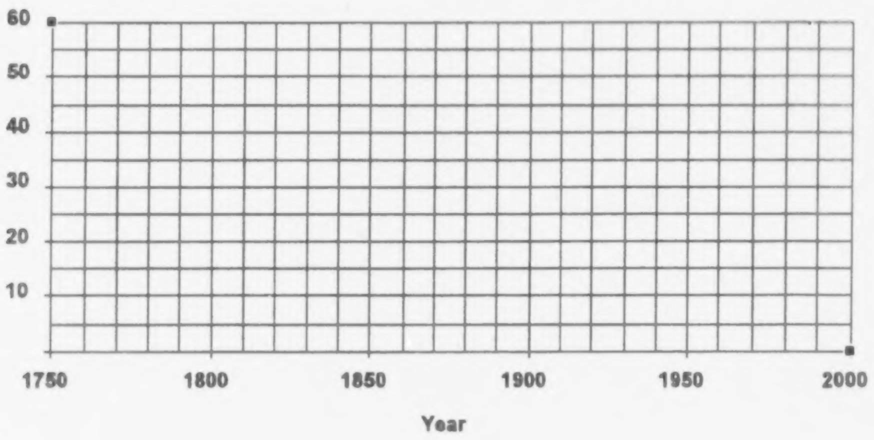
B. Plot the longitudinal data on crude birth rates (CBR) and crude death rates (CDR) for England's demographic transition. Use one color for CBR and a different color for CDR. Draw vertical lines showing approximately where the four stages begin and end and label the 4 stages. (Note that Stage 1 began prior to 1750.)

Table 7: Population Data for England, 1750-1993

England	1750	1800	1850	1875	1900	1925	1950	1975	1993
CBR	40	34	34	33	28	18	16	13	13
CDR	40	20	22	22	16	13	12	12	12
Population	6	9	18	26	32	40	44	49	50

Source: Data extracted from Rubinstein, James M. 1994. *The cultural landscape: An introduction to human geography*. Instructor's manual, 4th ed. New York: MacMillan.

Figure 12: Plot of Longitudinal CBR and CDR for England and India



Below are longitudinal birth and death rate data for India. We use them here to typify the demographic transition experience of a developing country and to compare it to that of England.

England is the main part of the United Kingdom (UK) of Great Britain and Northern Ireland, containing about five-sixths of the UK's population. England is where the Industrial Revolution began. India is the world's second most populous country and is expected to surpass China in the 21st century for the top spot. India is the world's largest democracy, though it is troubled by Hindu-Muslim-Sikh ethnic strife. And, of course, India was an English colony until 1947. For more background, refer to encyclopedias, regional geography textbooks, and maps.

C. On the same graph you created for England, plot India's CBR and CDR. Use the same colors as for England's CBR and CDR, but use dotted lines for India. Indicate with vertical lines approximately where India's demographic transition stages begin and end. Label the stages India-Stage 1, India-Stage 2, and so on to distinguish them from England's stages.

Table 8: Population Data for India, 1911-1994

India	1911	1921	1931	1941	1951	1961	1971	1981	1994
CBR	49	48	46	45	40	41	41	33	29
CDR	43	47	36	31	27	23	19	14	10
Population	252	251	278	318	361	439	548	684	912

Source: Data extracted from Rubinstein, James M. 1994. *The cultural landscape: An introduction to human geography*. Instructor's manual, 4th ed. New York: MacMillan. (Note: Data for earlier years not available.)

Now let's compare the demographic experiences of England and India on several aspects.

D. What differences do you notice in the speed at which their death rates declined? What might account for the difference?

E. What differences do you see in their rates of natural increase (the vertical gap between CBR and CDR)?

F. Plot the total populations of England and India over time on the graphs provided below. Draw smoothed population growth curves for each.

Figure 13: Total Population of India

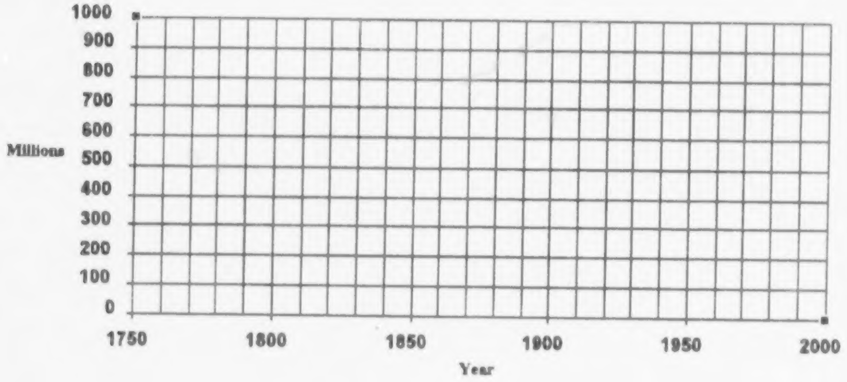
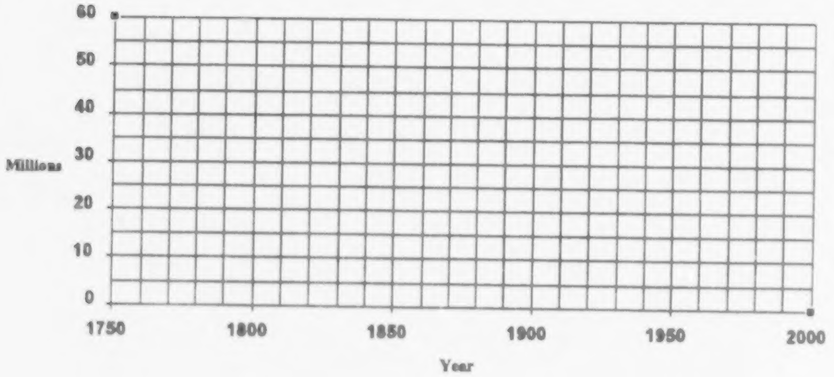


Figure 14: Total Population of England



G. Using the graphs you created above and those you created for questions B and C, compare the total populations of England and India at stimilar stages of the demographic transition. What options did England have at its disposal to deal with its changing population size that India has not had? What role did migration play in each country?

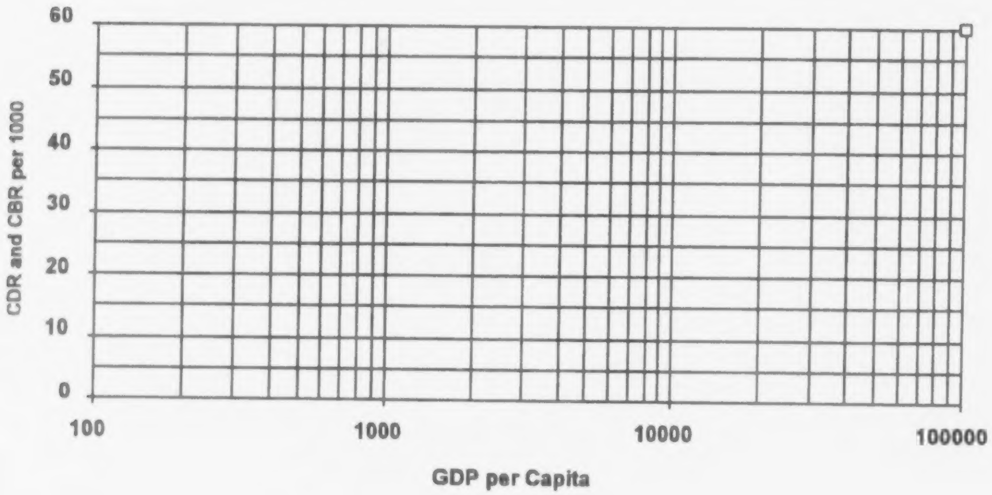
Part II: Cross-Sectional Analysis:
Can a Country Make the Demographic Transition without Development?

In this part of Activity 2.7, we look at birth and death rate data differently than we did in Part I. Instead of looking at one country over time, let's look at many countries at a single point in time. This is known as *cross-sectional* analysis. The idea is that different countries around the world are at different stages in their own development, and so we should see some countries at different stages of their own demographic transition. On the X-axis of the graph on the next page, we'll use Gross Domestic Product (GDP) per capita instead of time, based on the assumptions that (1) it is development rather than the passage of time *per se* that initiates the transition, and (2) that GDP per capita is a reasonable indicator of a country's level of development.

From the *World Population Data Sheet* or some other source of demographic data (such as the World Bank's *World Development Report),* choose a random or stratified random sample of 30 countries. A **sample** is a subset of the entire set (or, in statistical terms, the *population*) of members. In this case, a sample is a selection of 30 countries from the population of around 190 countries. A **random sample** is one in which every country has an equal chance of being selected, thus removing any conscious or subconscious bias the researcher may have in drawing a sample. The first step involves developing a **sampling frame**, or list, from which to choose. Then, a random sample can be generated by writing names of countries on strips of papers and pulling 30 out of a hat; by assigning each country a number and generating random numbers between 1 and 190; or by alphabetizing the countries and taking every 6th or 7th one (190/30 = 6.33). A **stratified sample** would contain a representative portion from each region or from each level of development, thus *ensuring* that all regions or income levels are fairly represented. Taking a stratified sample involves subdividing the sampling frame into subpopulations (e.g., continents or groups of countries according to average income level), figuring out what percentage of the total sample should be drawn from each subpopulation, and then devising a method to draw the required number randomly from within each sublist.

H. Begin by selecting a sample of 30 countries as described above. You may choose to select a random or a stratified sample of the countries of the world. On the following graph, plot the birth and death rates of the countries in your sample (using a different color each, for CBR and CDR) on the Y (or vertical) axis and the per capita GDP on the X (or horizontal) axis. Thus, for each country, you'll have two dots, whose (x, y) coordinates are: (GDP per capita, CBR) and (GDP per capita, CDR). Write the country names above the dots so you will be able to identify which country is which. Note that the X-axis for per capita GDP is logarithmic so as not to compress all of the poorer countries into the far left of the diagram. Starting at the left, the vertical lines are at \$100, \$200, \$300, . . . \$900, \$1000, \$2000, \$3000, . . . \$9000, \$10000, \$20000, \$30000, . . . \$90000, \$100000.

Figure 15: CBR and CDR of Selected Countries



I. Draw two smoothed curves, one that fits the general trend of the CBRs and the other that best fits the CDRs. Do not simply connect the dots, nor simply draw a straight line through the dots. Instead "eyeball" a curve that best approximates your dots. Most of your dots will not be on the curves themselves which is to be expected: there are other factors besides GDP that drive the transition. Draw it in pencil. Draw a curve from left (less developed) to right (more developed) with approximately equal number of dots on both sides of the curve. Then, do the same for the other curve. Finally, try to divide the graph into the different stages of the demographic transition (all four stages won't necessarily be represented in your sample of countries).

J. Now assess how well the demographic transition theory fits your cross-sectional data. Do CBR and CDR have the expected relationships with respect to development, as measured by GDP per capita? Does your data support the Third World's claim that "development" is the best contraceptive?

The next two questions focus on the general pattern (i.e., the smoothed curves) and the exceptions to this pattern.

K. Are there any low-income countries that have managed to achieve a low CBR despite their low level of economic development? Speculate (or do some research) on how they may have acheived it.

L. Are there any high-income countries that have not yet experienced the drop in CBR expected of developed countries? If so, what might explain their lag?

M. Many of the least-developed countries have low or even negative GDP per capita growth rates; what does the cross-sectional graph suggest about when *low-income countries* may complete the demographic transition and stop their population growth?

Student Worksheet 2.7 Name:

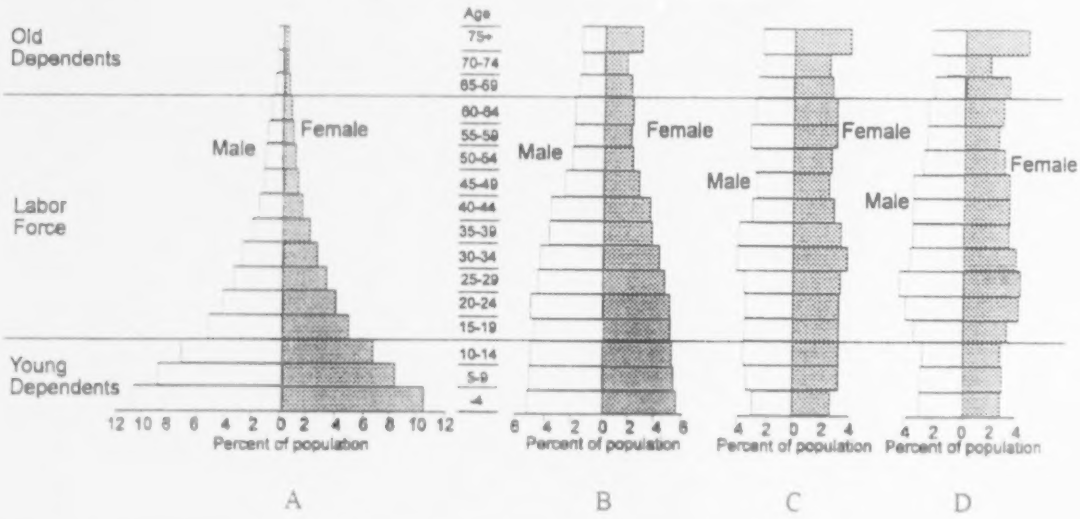
Activity 2.7 Simulating the Hidden Momentum of Population: A "What-if" Scenario for Mexico

In this activity you will learn about a common way to display population data graphically: the population pyramid. Population pyramids tell us a lot about whether or not a population is growing, and how fast or how slow it is doing so. This type of graph is also a good way to show the "hidden momentum of populations" and to clarify why population projections are so difficult to make.

Part 1: Population Pyramids

The "population pyramid" is a two-sided bar chart showing the number of people in each age group *(cohort)*, by sex. The horizontal axis measures number of people (or, alternatively, percent of population), while the vertical axis measures age (or, alternatively, year of birth). Here are some examples:

Figure 16: Population Pyramids



Source: Adapted from Fellman, J., A. Getis, and J. Getis. 1995. *Human geography: Landscapes of human activities*, 104. 4th ed. Dubuque: William C. Brown.

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A. Which population do you think is

(1) growing rapidly ______________ (2) stable ______________

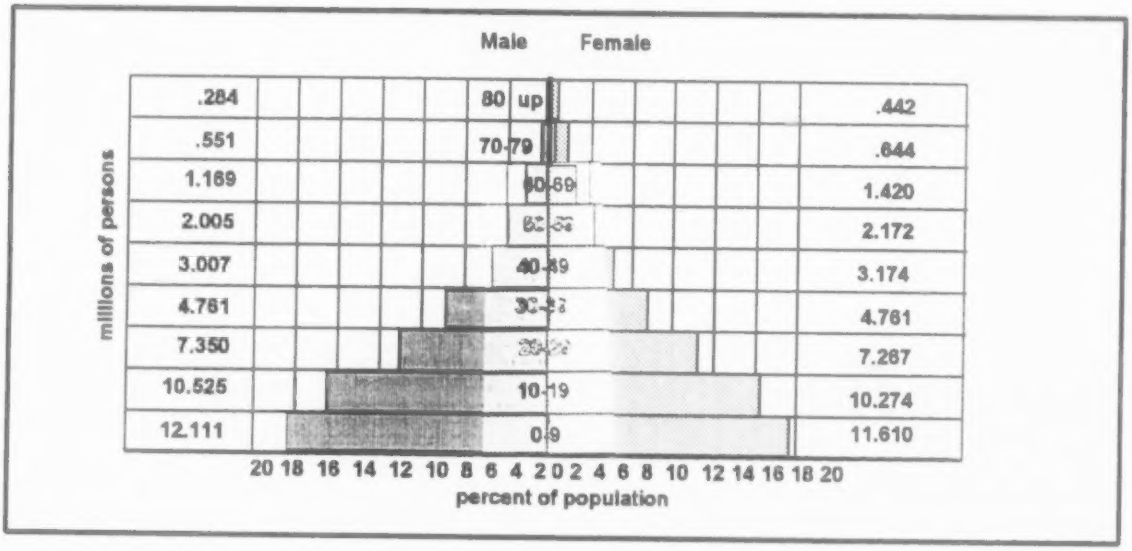
(3) growing slowly ______________ (4) declining ______________

B. How can you tell?

Part 2: Hidden Momentum

For this part of the activity, we use the population pyramid for Mexico shown below. Mexico is a medium-growth country in the third (late expanding) stage of the demographic transition. In 1990, Mexico had a total population of 83.53 million.

Figure 17: Population Pyramid for Mexico, 1990



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Information contained in population pyramids can be used to simulate the growth and population structure of Mexico in the future. Before we can simulate Mexico's future population, let us clarify some of the indicators you will need: total fertility rate and replacement fertility rate.

A country's *total fertility rate* (TFR) is the average number of children a woman will have during her lifetime, assuming that current age-specific birth rates remain constant throughout her childbearing years, which are usually considered to be ages 15-49. Mexico's TFR in 1990 was 3.8.

The *replacement fertility rate* is the average number of children a woman would have if the population were to remain at a stable level over the long term. It is called the replacement rate because it implies that each couple will have two children who will replace them when they die. However, the *replacement fertility rate* is not exactly 2.0 children per woman of child-bearing age. It is higher than that, around 2.1 to 2.3 children. If women have exactly 2.0 children each, the population will eventually begin a gradual decline.

C. Why do women would need to have more than 2 children each, on average, to keep the population level stable over the long term?

Demographic momentum (population momentum or hidden momentum) is the tendency for a population to continue to grow long after replacement level fertility rates have been reached. This phenomenon is due to the predominantly young age structure inherited from the period when the population was growing very rapidly, i.e., its fertility rates were still high. The resulting triangular type of pyramid has more children and more women in the early stages of their childbearing years. Even assuming that all of these young people have only two children each, the number of children they produce will be greater than the number of older people dying, because there are simply very few old people at the top of a triangular pyramid.

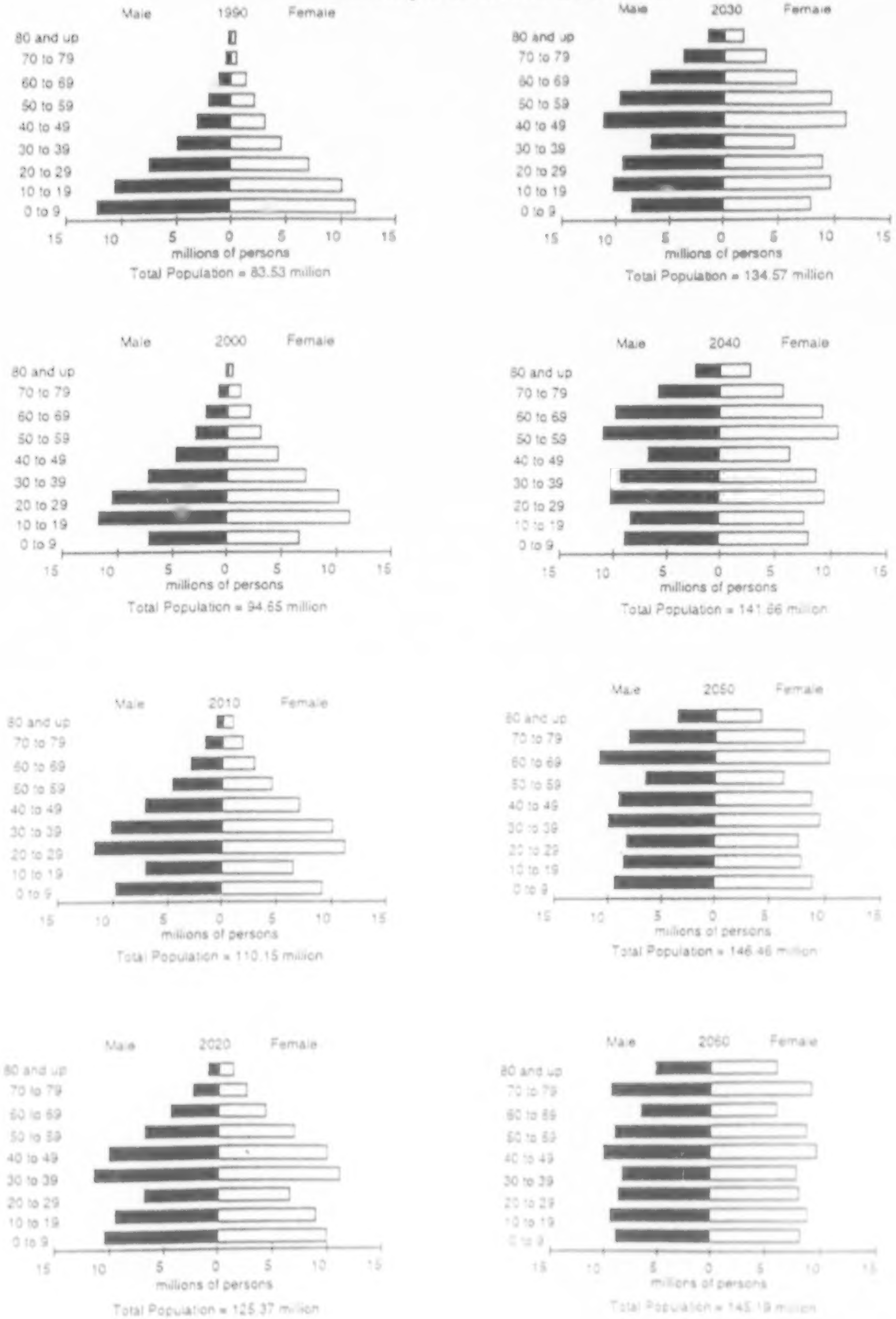
To demonstrate the hidden momentum of population, we will set up a controlled "experiment." Let's assume that suddenly, as of 1990, Mexican women began to have no more than two children each, either because of strict enforcement of a new law or because of a sudden, very firm value and behavioral change in Mexican society. Our assumption of a sudden replacement fertility rate of 2.0 is an optimistic one, since it goes at least 0.1 beyond typical replacement fertility rate, and because no such change could possibly be accomplished overnight. The United Nations calls this the "Instant Replacement" scenario. Of course, cultures in the real world cannot change so quickly. Still, if hidden momentum keeps the population growing for many years in this optimistic scenario, then we might be able to conclude that, in a more realistic scenario where the fertility rate is brought gradually down to replacement level, Mexico's population would grow even higher and for a longer span of time. So, let's see how this scenario would play out: for how many years will the population continue to grow, and by how much will it increase?

Let's start with Mexico's population pyramid in 1990 shown above in Figure 17. Starting in 1990, new pyramids were generated every 10 years until 2060, when the population finally stops growing. The resulting eight population pyramids are illustrated in Figure 18 on the following page.

Here is a brief explanation of how these population pyramids are produced given the instant replacement scenario.

- First, we move the population of each age-sex bracket farther up the pyramid by 10 years, less the average number of deaths for males or females in that age bracket (known as the **age-specific mortality rate**). For instance, 73.7% of women age 70 survive to their 80th birthday, compared to 62.5% of men. We make the simplifying assumption that the population ages 80 to 89 does not survive into their nineties.
- Second, the number of new births is based on the **age-specific fertility rates** typical of a country in Stage 4 of the demographic transition (with a TFR of 2.0). Specifically, we assume .29 new children for each woman ages 10-19, 1.14 new births for each woman ages 20-29, and so on, adding up to a total of 2.0.
- Third, the new births are divided among males and females according to the typical sex ratio at birth, which is about 105 boys per 100 girls.

Figure 18: Population Pyramids for Mexico (1990-2060) --Instant Replacement Scenario



Total Population = 83.53 million

Total Population = 94.65 million

Total Population = 110.15 million

Total Population = 125.37 million

Total Population = 134.57 million

Total Population = 141.66 million

Total Population = 146.46 million

Total Population = 145.19 million

"Instant replacement" (fertility = 2.0) scenario for Mexico beginning in 1990, simulated in 10-year steps until population growth ceases. Assumes age-specific fertility rates similar to those in U.S. (fewer births to women over 40, more to women under 20).

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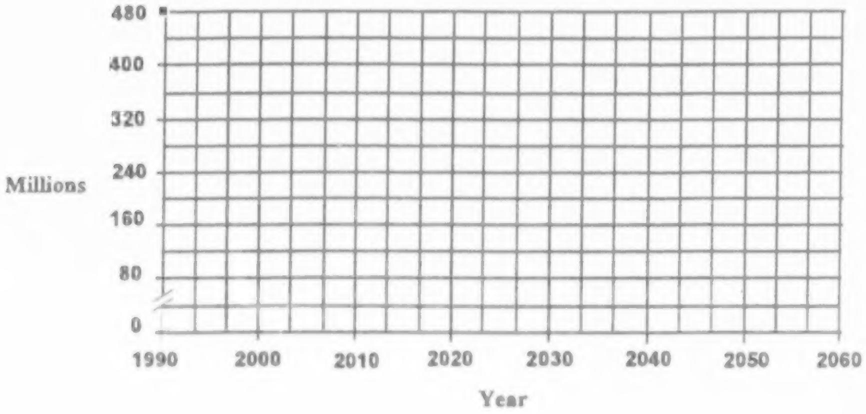
D. On the blank graph below, use the total population data found in Figure 18 to plot the estimated growth of Mexico's population from 1990 to 2060. Label the curve "instant replacement" scenario.

Figure 19: Mexico's Population 1990-2060



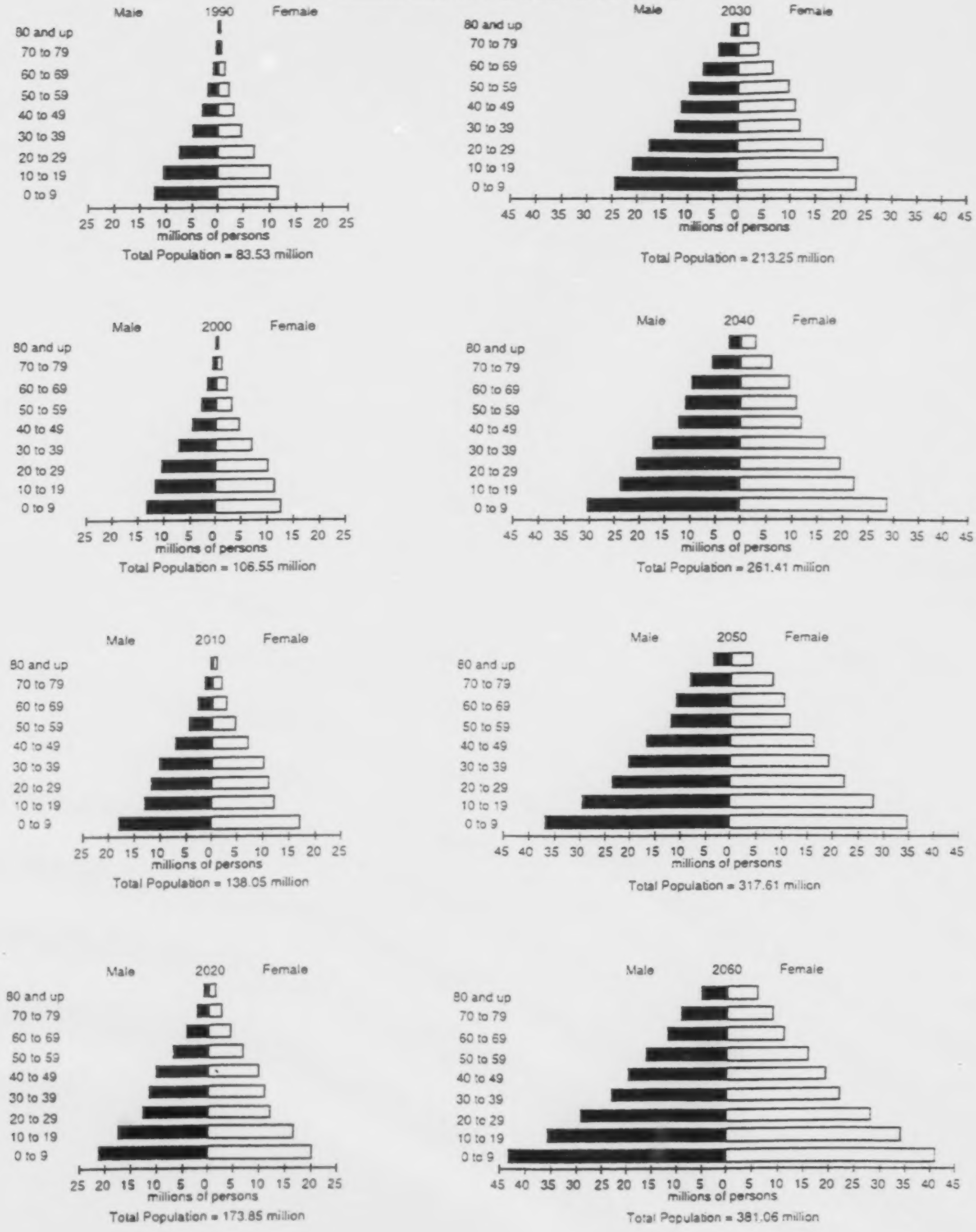
E. How much larger did the population get, both in absolute (millions of people) and relative (percent increase) terms before it stabilized?

F. Use a light-colored pen or marker to superimpose the 1990 pyramid over the 2050 pyramid in Figure 18. You can do this by eye, using the scales below the pyramids as a guide. What does this tell you about the source of the population increase in terms of age brackets?

G. If you asked the "man in the street" whether a country's population could continue to grow even after women started having only 2 children each, most would answer *"No, how could it possibly grow if each couple has only 2 kids?"* In light of the eight population pyramids, write a carefully worded explanation of the hidden momentum phenomenon, outlining how continued population growth would still be possible.

Next, we forecasted Mexico's future population pyramids under the "business as usual" scenario, that is, assuming Mexico's TFR remains at 3.8 (see Figure 20 below). Study these diagrams and compare them to the instant replacement scenario, and answer the following questions.

Figure 20: Population Pyramids for Mexico (1990-2060) --Business-As-Usual Scenario



"Business as usual" scenario for Mexico, assuming fertility remains at an average of 3.8 children per woman, simulated in 10-year steps until 2060. Note, x-axis scale is different than on the "instant replacement" diagram. Assumes Mexican age-specific fertility rates (more births to women over 40).

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H. Calculate the absolute growth (in millions) and the relative growth (in percent) under the business as usual scenario. Also, plot the population growth on the same graph as the instant replacement scenario (Figure 19). Clearly label the two curves. Write a brief paragraph comparing the two scenarios. Compare the size and shape of the 2060 pyramid under the business as usual scenario to that of 1990 and also to the 2060 pyramid under the instant replacement scenario.

I. What do you think is the most realistic scenario for Mexico's demographic future? Do you think it will be one of the two scenarios discussed above, or a different one altogether? Why?

The last question considers the implications of the hidden momentum of population. You have the opportunity to tie in concepts and ideas you learned earlier in this unit. Refer back to your answers if you need to refresh your memory.

J. Combine your understanding of the demographic momentum with the demographic transition theory's insights about what it takes to lower the fertility rate. In general terms, what do you conclude the two theories together suggest about when the world's population might stabilize, and at what level?

2 Population Growth

Answers to Activities

Activity 2.1 The Growing Years

Answers to this exercise are as follows:

A. Students will produce various tables and graphs of age and height based on their estimates of their growth over time.

B. No.

C. Steeper lines indicate periods of rapid growth. Horizontal lines indicate no growth.

D. Exact portions varying with student (generally as described in G).

E. Periods of growth tend to occur from birth through adolescence into early adulthood and taper off thereafter. A period of no growth follows, continuing through later middle age when minor height reduction occurs due to shrinkage. By age 80, shrinkage accelerates.

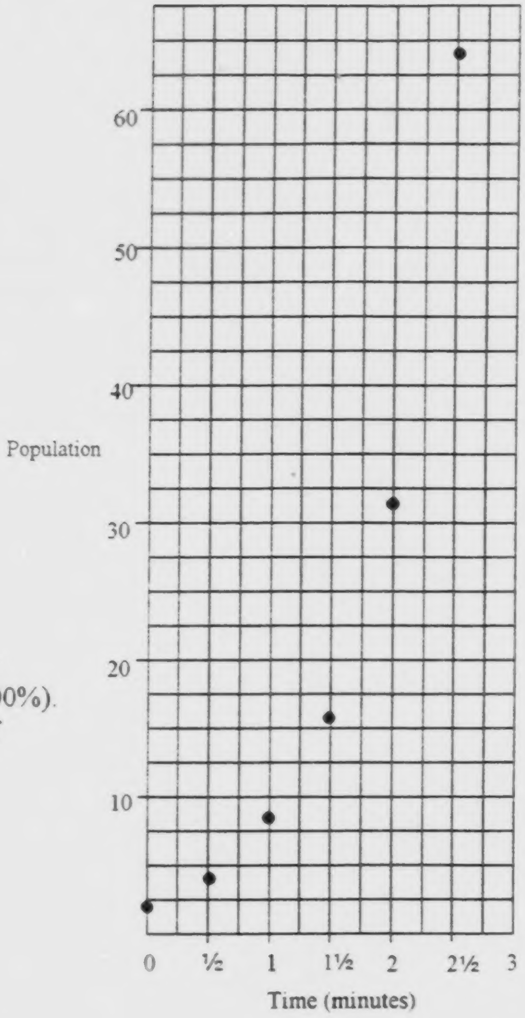
F. This graph would represent constant growth and appears as a straight diagonal line.

G. 132 inches or 11 feet.

Activity 2.2 Critters in a Jar

The initial graph and table are as follows:

Time	Population of Critters in Jar
0 min	2
30 sec	4
1 min	8
1½ min	16
2 min	32
2½ min	64



A. The process of filling up the jar with critters is slow at first, then accelerates (it takes 2 minutes to fill the jar to the half-mark, but it takes only 30-seconds more to fill it entirely). This is so because with each iteration the number of critters gets doubled (increase at time t+1 = 100%). The absolute growth over each next increment of time gets more dramatic.

B. 100%

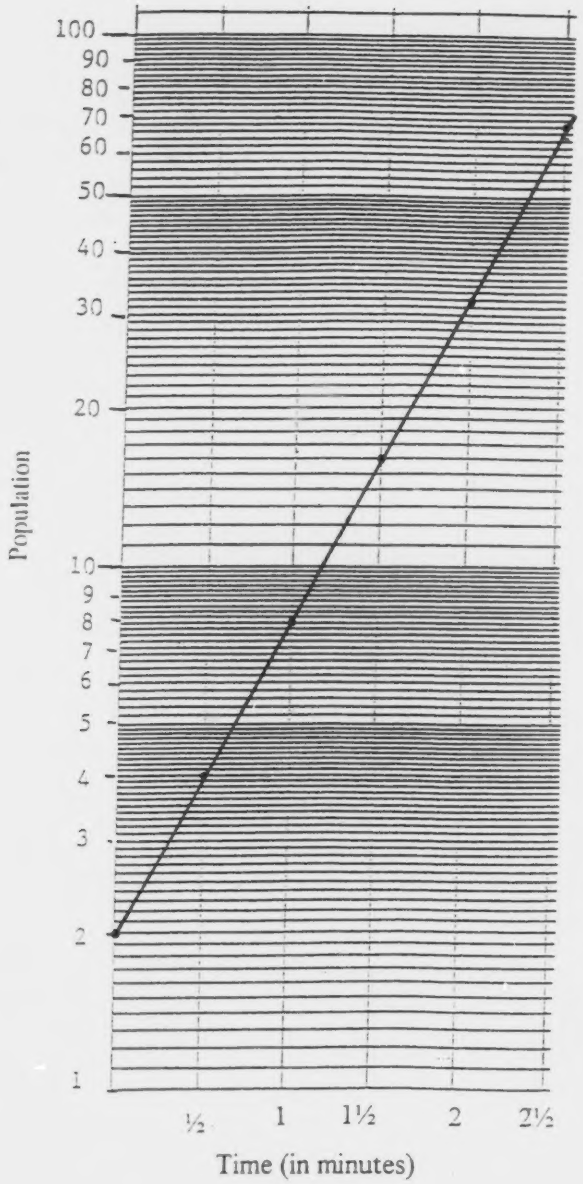
C. 2 minutes

D. 30 seconds

E. More dramatic

F. If the critter growth process was continued for an additinoal 2½ minutes, the data points along the *y*-vertical axis would shoot off the page because the absolute number of critters would increase so immensely.

G. The graph is shown at the right:



H. If the percent change had been different from one interval to the next, the line in the semi-log graph could not be a straight line but some kind of a curve, depending on the growth rates between each increment of time.

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Activity 2.3 Doubling Time

Answers to this exercise are as follows:

A. 1 minute.

B.

Year	Amount	Year	Amount (cont.)
0	1.0	10	1.4802
1	1.04	11	1.5395
2	1.0816	12	1.6010
3	1.1249	13	1.6651
4	1.1699	14	1.7317
5	1.2167	15	1.8009
6	1.2653	16	1.8730
7	1.3159	17	1.9479
8	1.3686	18	2.0258
9	1.4233		

C. $116 \times 2 = 232$
$232 \times 2 = 464$
$464 \times 2 = 928$
$928 \times 2 = 1{,}856$
$1{,}856 \times 2 = 3{,}712$
$3{,}712 \times 2 = 7{,}424$

In less than six doublings, Bangladesh's population would surpass 5.6 billion. Six doublings at 28 years each would be 168 years. Five doublings would be 140 years. It would take between 140 and 168 years. The exact answer is 5.6 doublings over 157 years.

D. Doubling time assumes that everything will stay the same -- birth rate, death rate, and no in- or out-migration. This is completely unrealistic over such a long period. After even a few doublings, let alone 5 to 6, Bangladesh (at present economic and agricultural capabilities) would be unable to feed its people, and starvation would first increase death rates and lower birth rates. In any case, Bangladesh's growth rate has already been gradually slowing down. Make sure that students understand that doubling time is a hypothetical "what if" statistic.

Activity 2.4 The Shapes of Populations to Come

Answers to this exercise are as follows:

A. The global population has not grown at a constant rate over time. One possible answer, regarding students' expectations about how human population has grown, might be: "since it was said that human population grows exponentially, I thought global population must have doubled every given time increment;" (i.e., a direct transference from critters to the global population). Another answer might be: "With all the wars, plagues, and other diseases, the changes in medicine and technology, I can't imagine that the population would grow at an even rate throughout history, even though the general picture is one of exponential growth;" (i.e., a careful "reality check" superimposed on knowledge of exponential population growth, but without consideration of limits to population growth).

B. Graph A implies that growth began around 2000 BC, and that any growth prior to that was insignificant.

C. Graph B implies that the human population actually began growing rapidly as early as 5000 BC, and that growth was detectable as far back as 10,000 BC.

D. Graph C suggests that population is in the process of leveling off -- that it grew slowly at first, then accelerated, and is now tapering off. This visual effect is caused by stretching out the time scale of recent years, especially the most recent 2-3 years. Basically, the graph bends the curve horizontally as we approach the present day.

E. Graph D shows how population growth began a major upswing right after the domestication of plants and animals. It then appears that population growth was gradually slowing prior to the scientific revolution, only to pick up speed again about 300 years ago.

F. Critique 1 -- Graph B
Critique 2 -- Graph D
Critique 3 -- Graph C
Critique 4 -- Graph A

Activity 2.5 "Be Fruitful and Multiply!"

5.702 billion × .015 = 85,530,000 per year
= 234,329 per day (rounded)
= 9,764 per hour (rounded)

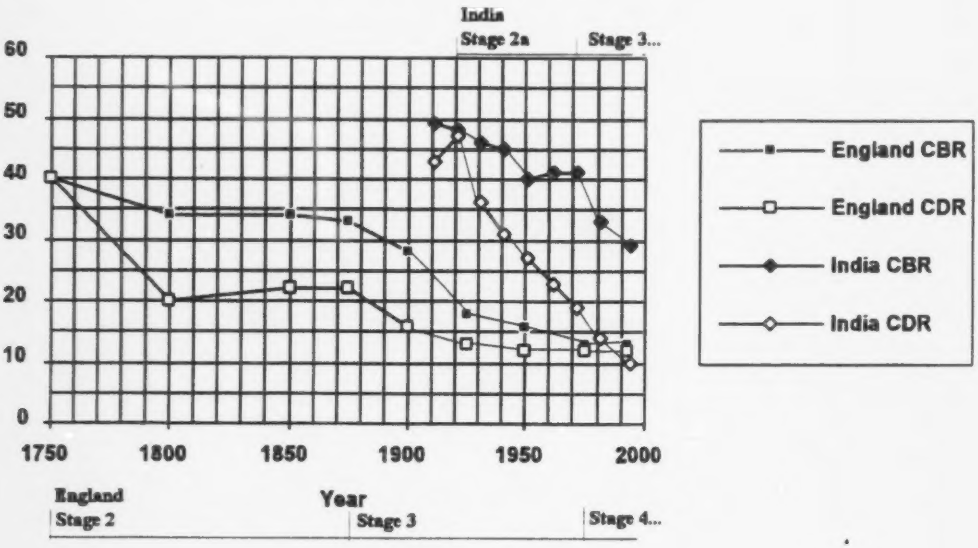
Activity 2.6 The Demographic Transition over Time and Space

Answers to this exercise are as follows:

Part I:

A. The death rate decline is mainly due to *innovation or diffusion of technologies* that increase life expectancy, particularly those in medicine, agriculture, sanitation, food storage, transportation, and communication. The list could be much longer. Innovations such as these tend to diffuse with little cultural resistance. Another important aspect (at least regionally and temporarily confined) is the end of war. (2) The birth rate decline tends to occur as the perception of children as economic assets in a rural-agricultural society changes to children as economic liabilities in urban-industrial societies. In a rural agricultural society, children can do much useful work like collecting wood and water, tending animals, planting and sowing, caring for younger children, and caring for the parents in old age. But in an urban-industrial society, children cost their parents money for additional food, clothing, housing, and education expenses, and there is less opportunity for them to contribute to a family's financial needs. Also, with the *advent of social security*, parents do not need to have as many children to be sure of a minimum level of old age care. The *transformation of women's rights* also contributes greatly to lowering birth rates because of access to general education (which tends to delay their marriage and child-bearing stages), education in sanitation and contraception in particular, and because of a sense of increased empowerment to affect family planning. There are numerous other factors, but these are considered most important.

B-C. The longitudinal plots for England and India are shown below.

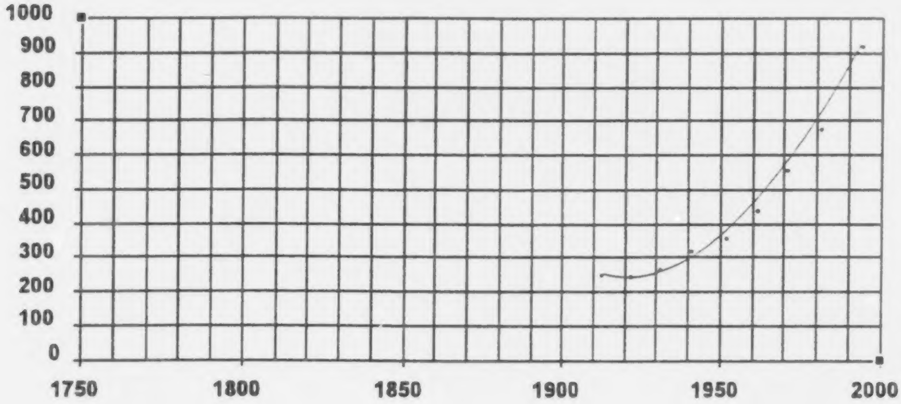


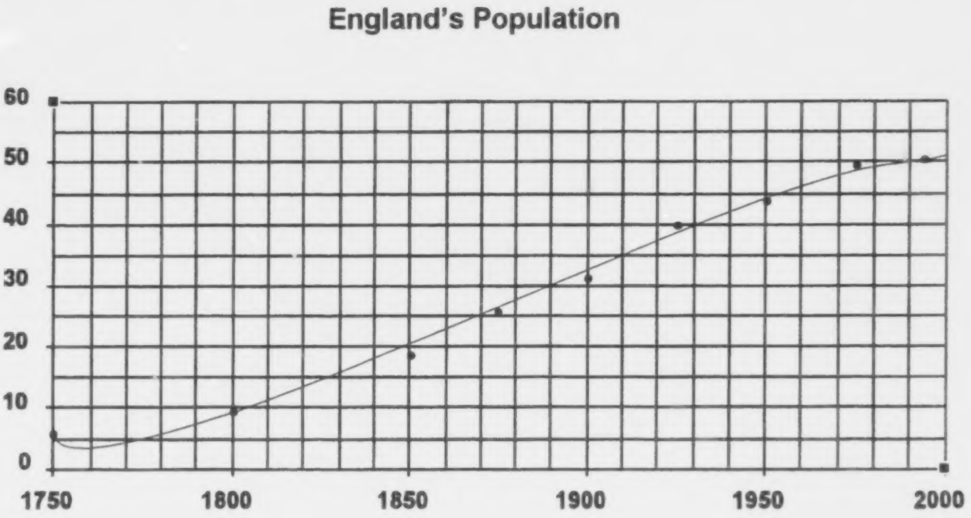
D. England has completed the demographic transition, while India has not. But India is not simply going through the same experience at a later date. The most noticeable difference is that India's death rate has declined far more rapidly than England's ever did. England's death rate fell gradually over 200 years, which meant that the birth rate never fell quite so far behind as it has in India. The difference in how fast the CDR fell is mainly the difference between innovation and diffusion. England's CDR fell slowly because the technologies for lowering the death rate were being innovated slowly. In India, most of the technologies were developed in the West, and the diffusion took place rapidly.

E. Because India's CDR fell so sharply, it has opened up rates of natural increase that are higher than anything ever experienced in England. Also, in India, the CBR and CDR started out at much higher levels, around 50 per 1000 compared with 40 per 1000. This also greatly increases the size of the gap between CBR and CDR once it opens up.

F. See the following two graphs of the population of India and England.

India's Population



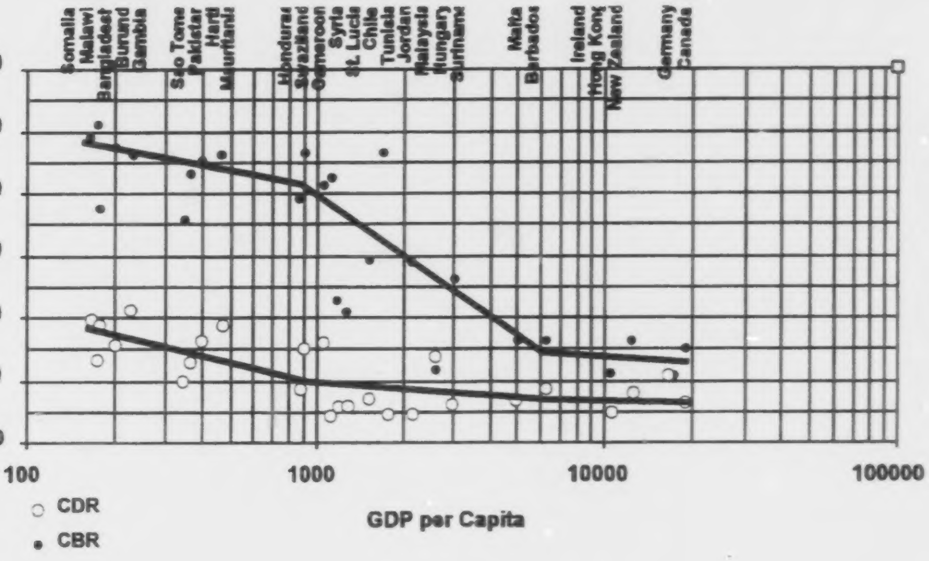


G. The graphs in question F show that India's population was already in the hundreds of millions by the time its transition started in the 1920s, whereas England's population at the beginning of the transition around 1800 was under 10 million. Of course, the countries are of different size, but preindustrial populations in the rice-growing parts of the world are already quite high when they enter the transition phases.

England had an outlet valve for its population: it sent its population excess to America, Australia, South Africa, Hong Kong, and, yes, India. India, on the other hand, has far fewer options in today's world for sending its excess population to settle in other countries.

All of these factors raise doubts about whether India will complete its transition before it experiences critical food supply shortages. The main positive difference for India is that its CBR has also fallen faster than England's ever did. Also, with greater awareness and education, it is possible that countries can lower the birth rates while remaining as predominantly rural and agricultural societies.

H-I. The graph below is an example of the type of graph students should create in response to questions H and I. Students' graphs will vary based on the countries they have selected in their sample. The module author's cross-sectional data were acquired from a stratified random sample. He chose every sixth country from the *1991 Population Data Sheet*, which gave him at least one country from every region, and more from regions with more countries.



J. The cross-sectional data confirm that, as countries get richer, the CDR declines first, followed by the CBR. Stages 2, 3, and 4 seem to be visible in the cross-sectional data, though only the very end of Stage 2. The early part of Stage 2, when the CDR plummets, has already happened everywhere in the world. There is a slight but noticeable decline in the CDR as GDP increases from the very lowest levels, but in the entire sample, only one country (Gambia) had a CDR over 20 per 1000. The transition from Stage 2 to Stage 3 occurs at GDP levels between $1,000 and $2,000 per person. With incomes less than $1,000 per capita, there are no CBRs under 35 per 1000 in the sample, whereas above $2,000 per capita, there were no CBRs above 30 per 1000. Death rates have not yet finished falling before the $1,000 GDP level. Stage 4 seems to be reached by the time a country achieves an income level of about $5,000 per capita. All sampled countries above this level have a natural increase under 1% (10 per 1000). So, apart from some exceptions to the general trend, and the total lack of Stages 1 and early 2, the data fit the theory quite closely.

K. A number of low-income countries have achieved lower birth rates than their GDP levels would suggest, such as Bangladesh, Chile, and the Caribbean country of St. Lucia (also China, which was not sampled). In the cases of Bangladesh and China, we can credit family planning programs. In the cases of Chile and St. Lucia, it may be the strong Western influences and the recent economic growth surges. Hungary is a different type of exception, in that it has a CDR>CBR, that is, its population is declining, despite a middle-income GDP per capita. This undoubtedly has to do with the uncertainty following the collapse of the Soviet Union.

L. Other high-income countries lag far behind other countries at similar GDP levels, such as Jordan. (United Arab Emirates, not sampled, also has a high CBR of 30 given its GDP level of $18,000.) The urban, industrial, and social development may lag behind GDP in traditional and/or oil-rich Islamic countries, but generalizations based on religion do not seem to stand up given that Bangladesh and Tunisia are both Islamic countries and they have birth rates lower than the general trend at that GDP level.

M. Completing the demographic transition and stopping one's population growth is not inevitable. It's not simply "a matter of time." Countries generally must become richer to bring the birth rates down. Authoritarian countries like China or traditional, Islamic, oil-rich countries like the United Arabic Emirates are among the very few exceptions to this rule -- the former with low income and low birth rates, the latter with high income and high birth rates. Some of the readings, however, suggest that low-income countries can lower their birth rates without being authoritarian and without becoming rich, by aggressive family planning policies and empowerment of women. It seems that the transition theory applies generally and in relative terms, that is, lower-income countries tend to have higher birth rates than those with higher incomes. But in an absolute sense, over time, it seems that low birth rates are being achieved at lower and lower absolute levels of development, which offers some real hope to the world.

Activity 2.7 Simulating the Hidden Momentum of Population: A "What-if" Scenario for Mexico

Answers to this exercise are as follows:

Part 1:

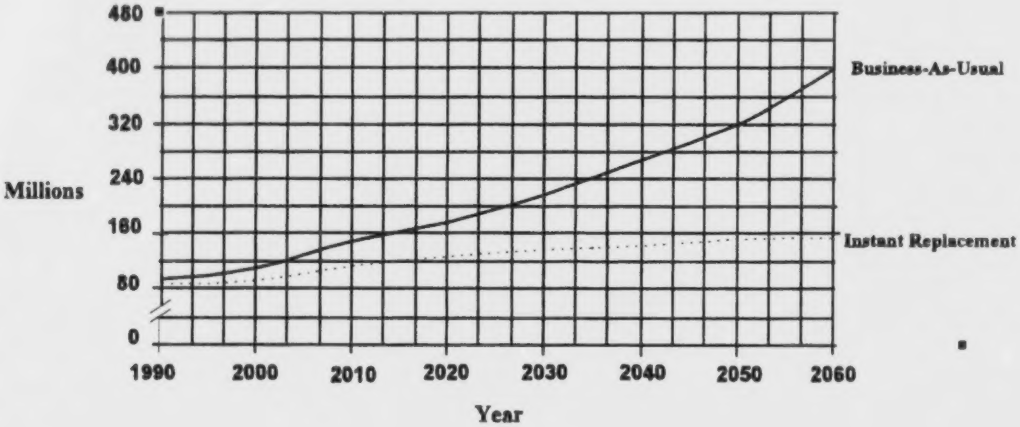
A. growing rapidly - A
stable - C
growing slowly - B
declining - D

B. Rapid growth: A broad base on a triangular pyramid indicates that each generation has produced more children than the last. Parents are having more than two children each and producing children's horizontal bars that are much larger than those in the parent's age brackets. Stability: A stable pyramid is indicated by a pyramid with relatively straight sides, meaning that the parent's generation has produced an equal number of children. Slow growth: A slow growth pyramid is halfway in between the broad-based triangle of the rapid growth population and a columnar pyramid of a stable population. Decline: A declining pyramid will be narrower at its base because the parents are not replacing themselves fully.

Part 2:

C. First, not all female children will live through their childbearing years. Infant mortality will claim some, while others though not many, will die in childhood or adulthood before having two children. Second, there are fewer girls born than boys. Since only females can bear children, the society must average slightly more than two children each in order to average at least one female child. An incorrect but not infrequent answer is that some women must average more than two to make up for those women who choose not to have children or are infertile. This is incorrect because the Total Fertility Rate already takes the societal averages into account.

D.



E. The population of Mexico grows for another 60-70 years, stabilizing between 2050 and 2060. The population in 2060 will have come down slightly from 2050, but since it was projected in 10 year increments, we cannot say for sure exactly when the downturn will have occurred. Mexico's population will hit a peak of 146.46 million in 2050, an increase of 62.93 million over 1990's population of 83.53 million. In percentage terms, 62.93 is 75.3% of 83.53, so the population increased by 75.3%.

F. There is a large gain in population among the middle-aged and elderly, who were but a small share of Mexico's 1990 population. For instance, the large number of people aged 70-79 in 2060 are the same people who were 0-10 years of age in the start year of 1990. The large gains of the 40-90 year-olds more than offsets the shrinkage of the children's cohorts by 2060.

G. Often students get confused about how a population can continue to grow even if the fertility rate of that population is at the replacement level because they compare the number of parents and the number of babies. To see if a population is growing, stabilizing, or shrinking, the correct comparison is between the number of births and the number of deaths; in other words, it's the age structure that matters, not matching numbers of parents and children. Most of the deaths in modern society are in the elderly age brackets, and in a rapidly growing population with a broad-based triangular pyramid, the percent of the population over 65 can be very small, averaging only 4 percent in the group of less developed countries. With so few old people, parents can have two children each and there will still be a far greater number of births than deaths.

The population will not stabilize until the pyramid has "filled out," meaning that it has changed its shape from being triangular to column-like, with the entire column approximately as wide as the base of the triangle when replacement fertility rates were reached. The growth of the population is attributable to the area of the pyramid filled in by the transition from a broad-based triangle to an equally broad-based column shape.

H. Absolute growth = 381.06 - 83.53 = 297.53 million
Relative growth = 297.53/83.53 = 3.562 or 356.2%

Under the business-as-usual scenario, with no change in fertility rates, the 2060 pyramid has the same shape as the 1990 pyramid, only bigger at every age. Although Mexicans are living longer, the pyramid remains a broad-based triangle because, in each new generation, each woman has an average of 3.8 children.

To compare the 2060 pyramids for the two scenarios, students should notice first that the X-axes are measured differently. The number of elderly are similar, but the business-as-usual scenario has 4-5 times as many children as the instant replacement scenario. In the instant replacement scenario, the pyramid undergoes a slow transition from triangular to columnar, which does not get completed until the children work their way through to old age.

I. It is unlikely that Mexico's demographic future will follow either of the two scenarios. It will most likely be somewhere in between the two extremes. Mexico's TFR has been dropping slowly, so it is unlikely to stay at 3.8 for 70 years. On the other hand, even China's one-child policy backed by an authoritarian regime did not achieve an instantaneous drop to replacement fertility.

J. Put together, the demographic transition and demographic momentum theories suggest that our hypothetical simulation for Mexico (which has the population growing ~74% for 60-70 more years) is actually a rosy prognosis both for Mexico and, generalized beyond this example, for the entire world. We might call that an optimistic, or lower-bound forecast, and even so, it implies a minimum world population of almost 10 billion by 2060. More than likely, we can expect another doubling of the world population (a 100% increase) taking at least 100 years to stabilize. Why? First, fertility will not drop to the replacement level overnight -- there will be a long delay in fertility rates falling to 2.1; in the meantime, the population will continue to grow, even before the hidden momentum delay begins. Second, Mexico's pyramid is less extreme than that of many developing countries, which have fertility rates higher than Mexico's 3.8 (in 1990) and even fewer old people. Third, the demographic transition theory assumes that economic development is just a matter of time, but recent history strongly suggests that the economies of many less developed countries are stalled, locked into a vicious circle of overpopulation, low investment, natural resource stress, export of raw materials, and dependence on imported energy and manufactured goods. This is especially true in some parts of Africa, Latin America, and South Asia.

3 Energy Use

Background Information

Introduction

Before we look closely at energy use as one important example of resource consumption with global environmental impacts, let's situate this topic within the overall context of this module. Recall that we began Unit 1 with a survey of perspectives on human-nature (or population-environment) relationships. We saw that there are those who argue that it is the sheer number of people on earth that determines this relationship, others who claim that it is what and how much these people consume that drives the interaction, and finally another group who see this relationship as a rather complex mix of population and consumption, mediated by technology and other factors.

In Unit 2, we focused on the basic dynamics of population growth to understand those who argue for the importance of the population factor. In this Unit, we do the same for resource consumption. Our resource example will be energy, mainly because it is so basic to all economic activity and because it is so intimately linked to the global climate change discussion. Let's begin with some basic economic concepts and their relevance to energy use.

Supply Issues vs. Demand Issues

As the cumulative environmental impact of energy production and consumption increases, global-scale changes become a real possibility. Unlike the 1970s *Limits to growth* paradigm, the current global change literature is mostly concerned about the flow of materials from the human economy into the atmosphere. At the same time, there is far less interest in whether enough energy can be sustainably produced (supplied) from renewable and nonrenewable sources to satisfy the needs of the human economy. One reason may be the slump in international oil prices since the mid-1980s, which has shifted attention away from supply issues, which were so prominent during the energy crisis of the late 1970s. Although some energy supply issues will be addressed here, the primary focus in this unit's activities is on energy demand issues.

Even if little attention is paid to the supply of energy, it is still a legitimate concern and highly relevant to energy consumption and pollution. The Persian Gulf War of 1991 was a harsh reminder of the precarious nature of oil supplies. Consumption occurs at the intersection of demand *and* supply of energy. As supply grows short, prices rise, sending signals to users to conserve or substitute, and to producers to search, innovate, and increase production. Likewise, the source of our energy and the size of its reserves are crucially important to long-term sustainability. Coal, for example, which emits more CO_2 and other pollutants when burned than does natural gas or oil, is 10 to 100 times more abundant than these other fossil fuels. These are but a few reminders that the supply side of the energy equation remains of utmost importance.

The demand side of the energy use equation is of course the most convenient link to the population discussion we had in Unit 2: the more people, the greater the demand for energy -- provided everything else (e.g., consumption levels or efficiency) stays the same. But, of course, over time "everything else" does not stay the same. People's values, behaviors, the availability and accessibility of energy-efficient technologies, the types of products and economic processes, and so on all change. Hence there is no simple linear relationship between the number of consumers and the level of consumption. How much is available to consume (or perceived to be available) affects consumption as well.

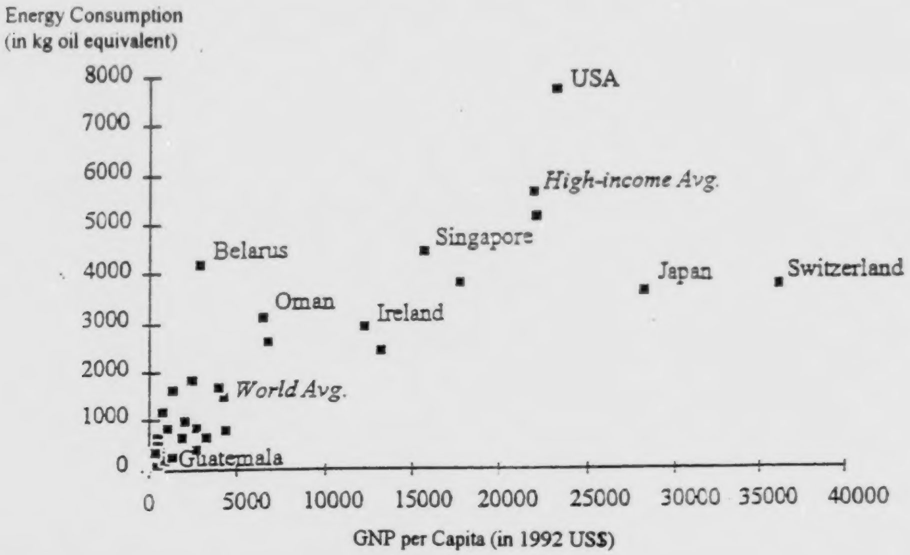
In the next section, we will see how energy consumption has changed over time and how that can be explained.

Trends in Energy Consumption

A possible starting point for studying energy consumption in society is the strong correlation between energy consumption per capita and **GDP** per capita. The linear relationship in Figure 21 below suggests quite strongly that it takes increasing amounts of inanimate energy (i.e., not from human or animal effort) to generate higher incomes. However, the interesting question for researchers and policy-makers is this: *Is the relationship in Figure 21 an economic law: i.e., is an increase in per capita energy consumption necessary for an increase in per capita income?, or is there room for maneuvering or even breaking the linear relationship...and if so, how?* In essence, the various activities in this unit are oriented toward understanding how much deviation is possible in this basic relationship.

The explanation for this relationship revolves around the concept of productivity. Productivity is a measure of output per unit of labor. Output can be measured in physical product, economic value, or value added, while the unit of labor can be a person-hour, -day, or -year. Productivity improvements, by definition, translate into higher **GNP** per capita. Assuming that the financial gain from greater output translates into higher wages for workers, productivity improvements are the basic mechanism for increasing per capita income. Since 1800, the productivity of the average American worker, and with it the American standard of living, has increased twenty-fold (Baumol, Blackman, and Wolff 1989).

Figure 21: Relationship Between per Capita GNP and per Capita Energy Consumption

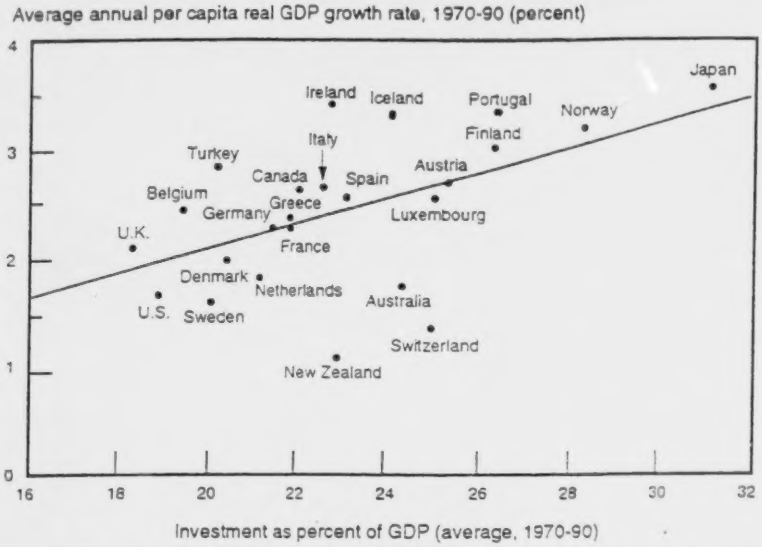


Source: Data extracted from The World Bank. 1994. *World development report 1994.* (Randomly selected countries plus Bank income-category averages.) Reprinted with the permission of Oxford University Press: Oxford.

The basic argument for why energy consumption must increase to improve productivity goes something like this. For a worker to produce more per hour, he or she generally needs to be equipped with more or better capital, although better education and training (a form of capital called *human capital*), a better work environment, or a better-functioning marketplace are also important. *Capital* here is defined as produced goods used to produce other goods, rather than as the financial wherewithal. Examples of capital that can improve productivity include computers, fax machines, highways, jackhammers, and all kinds of factory machinery. The concept of capital-for-labor substitution is an important one in the context of improving productivity. Consider the following example: in Trivandrum, India (and by no means only there!) women and children can be seen making gravel by hitting rocks with small hammers. The same type of work could be accomplished by machinery that is handled by very few people. So when capital is substituted for labor, one worker can produce the economic value formerly produced by 10, 100, or even 1,000 workers.

Evidence that capital investment does indeed drive economic growth can be found in Figure 22 below, taken from the *1995 Economic Report to the President* by the US Council of Economic Advisors. It shows a positive correlation between investment in new capital from 1970 to 1990 and growth of per capita GDP over the same time period. Generally speaking, the greater the percentage of GDP reinvested in new capital, the faster GDP per capita grew. The difference is not trivial. At about 3.5% growth, Japan's GDP per capita doubled during those two decades, while the USA's GDP per capita, growing at about 1.7% per year, would take twice as long to double. The results, with Japan having pulled well ahead of the U.S. in GDP per capita, could be seen in Figure 21 above.

Figure 22: Investment and Productivity



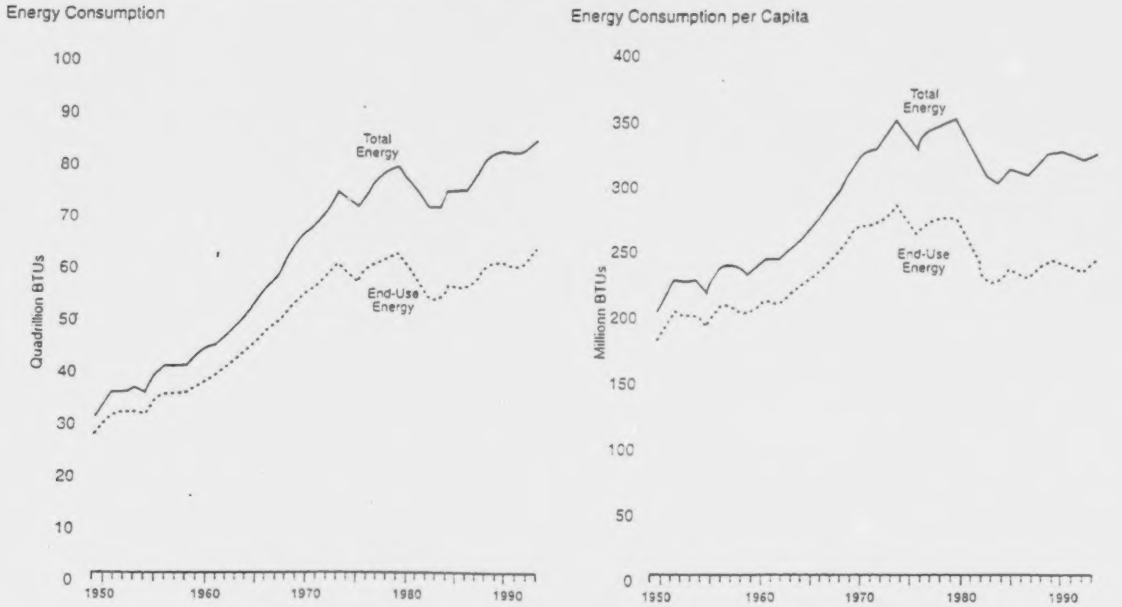
Source: U.S. Council of Economic Advisors. 1995. *Economic report of the President.* Washington, D.C.: U.S. Government Printing Office

To complete the standard argument that more energy consumption is necessary to increase GDP via improved productivity, it is simply necessary to point out that both creating and using capital require inanimate energy. Building a railroad and running a train take lots of energy, but with it, a crew of three can transport in days what would have taken months for thousands to carry by foot.

Although this argument explains the linear relationship in Figure 21, it does not account for countries located outside of this trend in Figure 21. Japan and Switzerland, for instance, have higher GNPs per capita than the US but just over half the American energy consumption per capita. The activities in this unit are designed to make us think about how these countries can be more productive than the US while they consume so much less energy. The United States appears to be one of the least energy-efficient countries in Figure 21, along with Oman and Belarus, though for different reasons. (You may want to take a moment here to think about why this may be so.)

The seemingly poor performance of the US in Figure 21 hides the substantial progress made in reducing energy consumption by the US economy since the mid-1970s. The two parts of Figure 23 show, while total energy consumption has been climbing since 1950 with only two major dips (one after the OPEC oil embargo, and one after the fall of the Shah of Iran), energy consumption per capita dropped steeply in the early 1980s and is still about 10% below its 1973 and 1978 highs -- even though the per capita GDP (not shown) has kept growing.

Figure 23: Total and Per Capita US Energy Consumption, 1949-93



Source: Energy Information Administration. 1994. *Annual energy review 1993.* Washington, D.C.: US Department of Energy.

Disaggregating energy savings and productivity gains into their independent components occupies much of the research work in this field. It is enormously complicated because there are so many variables changing simultaneously. Among the many factors involved in determining energy consumption and/or output per worker (and their growth) are:

- *import patterns* -- some countries like Japan or the Netherlands purchase most of their energy-intensive products like chemicals and aluminum from abroad, making their own economy seem more energy-efficient than it is;
- *structure of the economy*, in terms of what kinds of economic activities produce most of the output, and how much energy they use;
- *demographic structure*, including age and sex distribution;
- *capital intensity*, or how much capital there is per worker;
- *capital quality*, or how reliable and efficient the capital stock is;
- process or *"soft" technologies* relating to work organization;
- average years of *education of workers* (or human capital);

- *quality of education* -- high school graduates today (or in the US) may not be as well-educated as high school graduates of several decades ago (or as graduates in other countries);
- *research and development* effort;
- *climate differences*, measured in heating and cooling degree-days;
- *resource endowment differences*, in terms of availability and cost of energy;
- *geographical differences*, such as compactness of cities or concentration of economic activities;
- *cultural differences*, including consumption patterns, worker discipline, involvement of women in the workforce, race relations, political stability, and many other issues affecting both energy use and productivity;
- *technological catch-up*, whereby the fast-growing follower can close the gap with the slow-growing leader by adopting the leader's technologies; and
- *policy variables*, including energy taxes, capital gains taxes, income taxes, pricing, subsidies, regulation, government deficits, inflation, interest rates, pollution controls, and others.

There may well be greater potential for improvement in the US than in the rest of the world to catch up to Japan and Switzerland. Some have argued that even the most energy-efficient countries in the world could double or quadruple their energy efficiencies using currently existing or easily foreseeable technologies (e.g., Fickett, Gellings, and Lovins 1990). Studies completed for the US Department of Energy have suggested that the United States could obtain well over half of its total energy from renewable sources within 40 years (Idaho National Engineering Laboratory 1990).

This unit can only begin to touch upon these complex questions. The goal here is to provide the basic skills and conceptual understanding necessary to follow the ongoing debates on energy consumption, efficiency, and economic development. Much of our discussion builds upon two basic energy use diagrams -- one is an energy flow diagram of the US economy, showing the amounts of various energy types consumed for specified purposes at particular levels of efficiency, and the second is a unique kind of scatterplot that shows the energy use-GDP relationship over time and space on the same graph. In the following activities, we will explore these diagrams and what we can learn from them with regard to the linkages between energy use and economic development, and between energy and technology.

Closing the Circle

If it is generally true that an increasing amount of energy usage is essential to spur economic development -- not withstanding the variety of other factors that loosen this relationship -- then we can begin to appreciate the complexity and immense difficulty of the population-environment nexus.

Recall one of the arguments made earlier in Units 1 and 2 about how to slow or stop population growth: a large number of people are convinced that a combination of family planning, education of women, and economic development will halt population growth. Hence these measures will reduce the sheer influence that population has in causing environmental changes. This unit has taught us, however, that economic development brings with it an increase in energy consumption, which in turn leads to larger environmental impacts. The answer to that dilemma, we learned, is energy conservation and increased energy efficiency. Yet energy conservation alone, by whatever means, is insufficient when there are more and more people using energy.

While we haven't even begun to consider the implementation of policies and measures to reduce population growth or energy consumption in any local or national context, we can see already how one without the other cannot solve this global problem. Studying population dynamics and energy consumption leads us to conclude that multiple interacting forces cause global environmental impacts and that solutions must be equally comprehensive.

3 Energy Use

Instructor's Guide to Activities

Goal

The activities associated with Unit 3 are designed to raise students' awareness and understanding of energy use, its implications, and how energy use relates to economic growth. The exercises introduce a number of concepts and terms important to understanding energy use and explore the nature of energy demand and how it varies over time and space. Students will also become familiar with the role of renewable energy sources and various options to reduce energy consumption.

Learning Outcomes

After completing the activities associated with this unit, students should:

- have gained an awareness of their own energy usage;
- know various ways of measuring energy use;
- know what kinds of energy are used for what purposes in the US economy;
- understand the difference between energy elasticity and intensity;
- understand the difference between technological and structural change;
- be able to appreciate the role of renewable energy sources;
- understand the concept of demand side management; and
- understand the relationship between economic growth and energy use.

Choice of Activities

It is neither necessary nor feasible in most cases to complete all activities in this unit. Select activities that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. The degree of mathematical difficulty varies across the activities. The most difficult one is Activity 3.5, especially questions A-F in which students estimate the energy savings of demand-side management. You may wish to lend more assistance to students with this activity, or even do it as an in-class demonstration. This unit contains the following activities:

3.1 Shedding Light on Your Life	-- Assessing the energy usage associated with daily activities
3.2 Analyzing and Interpreting Energy Flow Diagrams	-- Analysis of graphical depictions of energy flows
3.3 Crawling to Efficiency--the Worm Diagram	-- Data plotting and interpretation of worm diagrams
3.4 What Needs to Change -- Technology or the Economy	-- Calculations of technical efficiency and group discussion

3.5 So...What Do We Do? Three Mitigation Measures -- Calculations of energy savings and group discussion or role play (various options)
3.6 Walk the Talk! Energy Conservation on Campus -- Capstone project investigating energy usage on campus and recommending conservation measures

Suggested Readings

The following readings are suggested to accompany the activities for this unit. Choose those that are most appropriate for the activities you select and those most adequate for the skill level of your students.

- Unit 3: Energy Use (provided)
  The background information to Unit 3 (all students should read)
- Lenssen, N. 1993. A new energy path for the Third World. *Technology Review*: 42-51. Reprinted in *Global Issues 94/95*, R.M. Jackson, ed., 113-119. Guilford, CT: Dushkin Publishing Group.

Optional Further Readings and References

Energy statistics for the USA

- U.S. Energy Information Administration. Annual. *Annual energy review*. DOE/EIA-0384(yr). Washington DC: US Department of Energy.

International energy data (including sources of international energy data used in this activity):

- International Energy Agency, *Energy statistics and balances of non-OECD countries*. Paris: OECD/IEA,
- International Energy Agency, *Energy balances of OECD countries*. Paris: OECD/IEA.
- U.S. Energy Information Administration. Annual. *International energy annual*. DOE/EIA-0219(yr). Washington DC: US Department of Energy.

Other important references

Readings and data on the supply side are voluminous. Estimates of reserves and undiscovered resources, drilling effort and success rates, etc., can be found in the US Department of Energy publications *Annual Energy Review* and *International Energy Annual*. The International Energy Agency, headquartered in Paris, is another excellent source. Basic data such as energy consumption per capita and per dollar of GDP is in the World Bank's *World Development Report*. An excellent compendium on energy is the September 1990 issue of *Scientific American*, which is devoted entirely to energy. There are articles by region, by type of energy, and by end use; Davis's (1990) article on "Energy for planet Earth" looks at the big picture. Another good collection is edited by Abeles, Jacobson, and Sheng (1992). An interesting perspective on energy supply is provided by Hall and Cleveland (1981), who argue that the ultimate limit on the extraction of fossil fuels is the point at which it takes more energy to extract them than they contain!

- Crabbe, David and McBride, Richard. 1978. *The world energy book: An A-Z, atlas, and*

statistical source book. Cambridge, Mass.: MIT Press. (A good, if dated energy reference book, with definition of hundreds of terms and energy conversion factors.)

- The September 1990 issue of *Scientific American* is devoted to energy, with some papers taking a regional perspective and others focusing on certain fuels or certain end uses.
- Abeles, B., Jacobson, A.J., and Sheng, P., eds. 1992. *Energy and the environment.* Singapore: World Scientific Publishing Co. (An interesting book containing a variety of viewpoints, including essays by Amory Lovins, a pioneer on energy conservation, and by Exxon researchers)
- Stobaugh, Robert, and Yergin, Daniel, eds. 1979. *Energy future: Report of the energy project at the Harvard Business School.* New York: Random House. (One of the landmark books on the energy crisis, though now a bit dated, was written by researchers at the Harvard Business School. In emphasizing energy conservation, they gave some legitimacy to the demand side management movement)
- Morgan, M.G. 1993. What would it take to revitalize nuclear power in the United States? *Environment* 35: 6-9, 30-32. Reprinted in *Environment 94/95*, J.L. Allen, ed., 185-188. Guilford, CT: Dushkin Publishing Group.
- Olsen, Marvin E. 1992. The energy consumption turnaround and socioeconomic well-being in industrial societies in the 1980s. *Advances in Human Ecology*, 1: 197-234. (An article that challenges the "energy and society coupling thesis" by identifying a number of industrialized countries that have decreased rates of energy consumption without necessarily sacrificing economic well-being.)

Activity 3.1 Shedding Light on Your Life

Goals

This activity raises students' awareness of their own energy usage or the energy usage in their immediate environment.

Skills

✔ maintaining awareness of one issue for an entire day
✔ critical observation and thinking
✔ team work (in some versions of this activity)
✔ informal interviewing (in some versions of this activity)
✔ communicating verbally and in writing

Material Requirements

- *Student Worksheet 3.1* (provided)
- *Supporting Materials 3a–b* and *3.1* (provided)
- Note pads
- Pens or pencils

Time Requirements

Alternative 1: 1-2 hours as homework

Alternative 2: 3-4 hours over a week
Alternative 3: 1-2 hours as homework
Alternative 4: 3-6 hours over a week

Tasks

Several alternatives are offered; all aim to raise student awareness of their own or their college's energy usage. Choose one, some, or all of the ideas listed below, assign different tasks to different (groups of) students, or choose whichever version promises to work best in your class.

Independent of the version of this activity that you choose, you may want to briefly introduce students to *What is energy? Where does it come from? Where does it go? How is it measured?* etc. Use the overhead originals *(Supporting Material 3a÷b)* provided to do so. If you assign the following activity as homework, you may want to save a few minutes for this introduction at the end of the session preceding this homework.

Alternative 1: Hand out copies of *Supporting Material 3.1* to students and ask them to keep track for one whole day -- from the minute they get up in the morning to the minute they turn off the light at night -- of when, where, how, and for what they use energy. This "daily energy log" may be written up in chronological or topical order (e.g., food preparation/transportation/school work etc.) Ask students to write a short reflection paper on their own energy usage as documented in their daily energy log.

Alternative 2: Assign groups of students to contact the regional utility company/ies to find out where the electricity that we all use comes from. What resources provide the raw energy from which the electricity is generated? If not locally produced, where does this raw energy source come from? What is the relative share of each source? etc. Students should report back to the class with their findings. Assign another group of students to research the same questions for the United States in general (see the references and information sources given at the beginning of Activity 3). In class, make a table on an overhead or the blackboard which compares the local/regional and national energy sources and shares. Discuss the differences and what might explain them. What, if anything, do the differences tell about regional energy sources, usage, and policies?

Alternative 3: Ask students to make a complete list of all the energy-consuming tools, vehicles, and machinery that they use or benefit from on a normal day (at work, at school, for transportation, entertainment etc.). (*Supporting Material 3.1* may also be helpful here). Ask them to critically rate each one of these items as "E" (essential), "H" (helpful; makes my life much easier), "L" (luxury), "RA" (replaceable by a more energy-conserving alternative), or "NBA" (neither essential nor luxury, but there is no better alternative). Note that individual items may be given more than one rating. After they have made their list, ask students to reflect in a 1-page paper on what they discovered, what was most surprising or disturbing about this list. Use this as the basis for a short in-class report and discussion.

Alternative 4: Ask students to observe how energy is used (and wasted) at their college or university. At this point, students will only collect information (which at some later point they may come back to for a larger project!): How is energy used? How much does the university spend on electricity? How much on heating and cooling? What kind of light bulbs are used in classrooms, in the dorms, in the gym? Are the lights turned off after students leave the classroom? Are the windows open or closed while the heat or air conditioning is on? Are there any energy conservation programs in effect at the college? Who is in charge of making decisions about implementing such programs or the kind of equipment that is bought?

After students have collected the information, ask them to discuss in small groups of 3 or 4 what they found, what they liked or did not like about energy use at their institution, what they would like to see changed. You as the instructor may need to alert the person in charge at the college that you have assigned this activity. Ask the class to send a delegation of a few students to talk to this person rather than having the entire class make phone calls or pay individual visits.

If you so choose, this information could be the basis for a continuing project with your class. If you have raised students' awareness -- by way of observing energy usage and waste -- for the need of energy conversation, you may want to build on their interest by encouraging them to write an *energy conservation proposal* to the college's administration. This could be a capstone or end-of-term project that feeds on all other knowledge and skills gained during this activity, module, or course. The more real the task, the more enthusiasm and self-propelled engagement you will find!

Activity 3.2 Analyzing and Interpreting Energy Flow Diagrams

Goals

Students get an overview of U.S. energy sources, stages, and uses, and learn how they can be summarized in an energy flow diagram.

Skills

✔ interpreting energy flow diagrams
✔ analytical and critical thinking

Material Requirements

- *Student Worksheet 3.2* (provided)
- *Supporting Material 3.2a+b* (provided; make copies in sufficient numbers)
- *Supporting Material 3a-c* (provided)

Time Requirements

30 minutes

Tasks

This exercise can be done as homework or as in-class work, either individually or in pairs. Remind students (using *Supporting Material 3a+b* as overhead originals or hand-outs) of the definitions of energy and energy use. This activity allows students to apply these definitions to, and recognize them in, a graphical depiction of energy flows through the US economy (*Supporting Material 3.2a+b* for 1982 and 1995, again, as overheads and hand-outs).

Give students a few minutes to become familiar with the flow diagrams, then ask them to pair up with a neighbor and explain the diagrams to each other: What do they show? What does the size of the arrows indicate? What are the energy sources? Where does the energy come from? What is it used for (the main uses/branches)? How do the two diagrams differ? The instructor facilitates only where necessary by helping students ask the right kinds of questions of the diagram and each other. Then allow several minutes for them to answer the first three questions. Give them an opportunity to explore these diagrams and discover them on their own.

Next explain the term *elasticity* (using *Supporting Material 3c* as an overhead) and let students discuss in pairs and answer the last question on the *Student Worksheet* relating to the energy flow diagrams.

Activity 3.3 Crawling to Efficiency -- The "Worm Diagrams"

Goals

Students learn about the relationship between economic growth and energy use using two important concepts -- energy intensity and energy elasticity. Students also compare this relationship as it varies across countries.

Skills

✔ plotting data on log-log paper
✔ analytical thinking
✔ conceptual understanding

Material Requirements

- *Student Worksheet 3.3* (provided)
- Colored pencils (optional)

Time Requirements

Allow at least 10 minutes for making the graph, and an additional 30 minutes for answering the questions. If you cannot spare that much time in class, start the drawing of the worm diagram in class and assign its completion and the questions as homework. Alternatively, provide a completed worm diagram (using the one provided in the *Answers to Activities* for this activity) and do the questions in class together.

Tasks

Allow students a short time to read the introductory text and look over the data provided for Activity 3.3. Make sure students feel comfortable with the economic and energy-use indicators used here. Using the worm diagram provided, ask students to complete the diagram by adding Iran and Japan to the other eight countries already shown. Make students aware that they are using log-log paper and point them to Unit 2 if they want to refresh their memories.

The plotting should not take more than 10 minutes. They may use different colored pencils to mark the points and the worm-boundaries around them for each country (alternatively, use different marker styles, such as *, +, #, ✦, □, ✗, ●, ▲, ▼, or ①). While each student should have a copy of the worm diagram, they may answer the questions either individually (in-class or at home) or in pairs.

If students seem to have difficulty with finding the correct answers, the instructor may examine the problem with the entire class.

Activity 3.4 What needs to change -- Technology or the Economy?

Goals

Students learn about two of the main ways to lower the energy intensity of a country: technological change and structural change.

Skills

✔ applying basic math skills to the calculation of energy efficiency
✔ critical, analytical, and imaginative thinking
✔ interpreting a graph of the structure of the US economy over time
✔ using structural-economic and geographical factors to explain international differences in energy intensity and efficiency
✔ group discussion (listening, formulating arguments, debating, finding consensus)

Material Requirements

- *Student Worksheet 3.4* (provided)
- *Supporting Materials 3.4a-c* (provided; make copies in sufficient numbers or use as overheads)
- *Supporting Material 3d* (provided)
- Calculators (alternatively, basic math skills suffice)

Time Requirements

30-45 minutes

Tasks

Familiarize students with the concept of technological change (use *Supporting Material 3d*). Before they start answering the questions on the *Student Worksheet*, ask them to brainstorm about how technological change may both increase and decrease energy consumption. Allow this to be non-judgmental and imaginative. Gather their answers in a two-column table on the blackboard or on an overhead transparency. When you have a number of answers on both sides, ask them whether the examples in each column have anything in common (types of technologies, types of technological changes, types of uses these technologies are put to, etc.). What does that say about where we are going or ought to be going? How likely do they think these changes are to occur? Take a poll.

Then allow a few minutes for each student to read the introductory text on technological change and calculate the answers to the first two questions. For the third question on technological change, students may pair up with a neighbor or work in small groups. Hand out sufficient numbers of *Supporting Material 3.4a*. If students work in small groups, stage the activity as a meeting between technology and engineering experts whose task it is to revolutionize the US home appliance sector by dramatically increasing energy efficiency.

Then explain the concept of structural change (use *Supporting Material 3d*) and allow a few minutes for students to read through the introductory text on structural change. Using *Supporting Material 3.4b and c*, students discuss in small groups of three or four the structural changes in the US economy over the last 100 years and how that relates to energy intensity. All students in the group should take notes, but the instructor may also assign roles such as discussion leader and process observer to individual students (see the *Notes on Active Pedagogy* for more information on these roles and their functions in group work).

The last three questions of Activity 3.4 may be answered in a similar fashion (group discussion and note taking) or they may be given to students to finish as homework.

Activity 3.5 So ... What Do We Do? Three Mitigation Measures

Goals

Students learn about sustainable energy solutions, not just energy problems. In particular, they learn about demand side management, renewable energy, and lifestyle changes as three ways to reduce energy consumption and/or its environmental impact.

Skills

- ✓ conceptual understanding
- ✓ analytical thinking
- ✓ applying basic math skills to calculating energy savings through demand side management
- ✓ group and/or discussion (listening, formulating arguments, debating, finding consensus)

✔ role play (in one version of this activity)
✔ critical self-assessment of behaviors and thinking patterns

Material Requirements

- *Student Worksheet 3.5* (provided; students should have answers to Activities 3.2 + 3.4)
- *Supporting Materials 3.5a-d* (provided; make copies in sufficient numbers)

Time Requirements

20-30 minutes for Part 1 on Demand Side Management
15-20 minutes for Part 2 on Renewable Resources
15-30 minutes for Part 3 on Lifestyle Changes (depending on the alternative selected)

Tasks

Ask students to read through and solve the problems posed in the section on demand side management. After about 15 minutes, have them compare results with a neighbor and try to resolve together all conflicting answers. The instructor should intervene only where necessary and make sure at the end of this period that all students have the correct answers. This is the most difficult activity in terms of math -- not so much in the types of calculations (which are mostly percentages) but in terms of figuring out what numbers to use. Each pair of students should end this section by discussing their answers to the last question on why utility companies are moving toward demand-side management.

For the next section, students may refer to their "Daily Energy Log" (if they did this version of Activity 3.1) to recall the knowledge of renewable energy sources that they already have. Hand out copies of *Supporting Materials 3.5a, b,& c* to answer the next set of questions.

Ask students to use the space below Question L of the *Student Worksheet* (regarding lifestyle changes) only for note taking and brainstorming. Then engage students in a discussion and exploration of this topic in one or more of the following ways:

Alternative 1: Group discussion -- Students form small groups of four and exchange the ideas they came up with while brainstorming. After each student has had a turn, they discuss what lifestyle changes they think would be most effective in terms of reducing energy consumption and which they think would be most easy to make. Which ones are they likely to stick to permanently? Would they make a public commitment to each other of making at least one change? If they agree to do so, they should have some time after a couple of weeks to check in with each other on how they're doing. After about 10-12 minutes of discussion in which there is a reporter, a discussion leader, and a process observer (see *Notes on Active Pedagogy*), have one in the group report to the rest of the class what they came up with. If you had students do a similar activity earlier (see Starter Activities in Unit 1), this may be the best opportunity to learn about students' experiences as they chronicled them in their diaries.

Alternative 2: Panel discussion -- instead of small-group discussions, stage a panel discussion between maybe five or six representatives of various groups (right wing, left wing political groupings, church leaders, grass roots environmental groups, a speaker for families, a college administration representative, etc.). Encourage students to be controversial, taking conservative, progressive, liberal, individualistic, communal, and other points of views in debating what we could do to change our energy-consuming lifestyle.

Alternative 3: Role play -- especially workable in smaller classes. Ask students to decide on a typical setting where discussion about lifestyle changes might take place, e.g., at home with their families at the dinner table, among students in a cafe or bar, with neighbors during a backyard party. Divide up the roles, assign standpoints on the matter, then give the players a few minutes to think through their ideas and decide how best to convince the other players of their position. After the role play, have a short debriefing with the entire class on how convincing they felt each player's position was and what they learned in the role play.

Alternative 4: In-class poll-taking -- an exercise that works well in larger classes. Ask students to prepare a list of the ten lifestyle changes they think are most important for reducing energy consumption. After a few minutes, the instructor gathers these on the blackboard or an overhead transparency. Then have a vote on each item with four possible ratings: "most important," "good but not crucial," "negligible," and "don't know." After the voting, have the class give comments on the outcome of this vote. Do they think the class is on target? Why or why not? What would that mean for their personal lives? Will they consider changing their lifestyles? Would they publicly commit to it (see Alternative 2)?

Activity 3.6 Walk the Talk! Energy Conservation on Campus

Objectives

Students engage in practical problem-solving by applying the research, writing, and presentation skills gained in this course.

Skills

✔ working cooperatively and collaboratively with classmates
✔ gathering energy conservation information
✔ constructing convincing arguments from empirical information and problem understanding
✔ finding practical, local solutions to an abstract national/global problem
✔ writing a public report or "proposal"

Material Requirements

- *Student Worksheet 3.6* (provided)
- Notes from Activity 3.1, Alternative 4 (done by students previously)
- Access to libraries, phones

Time Requirements

1-3 weeks

Supplementary Resources

The following books are some good starting points for students to find information on alternative energy technologies, suppliers, and other general information on how to save energy and on how energy and technological solutions relate to climate change:

- International Energy Agency/Organization of Economic Co-Operation and Development. 1994. *IEA/OECD Scoping study: Energy and environmental technologies to respond to global climate change concerns*. Paris: OECD.
- Schaeffer, John et al. (eds.). 1993. *Alternative energy sourcebook: A comprehensive guide to energy sensible technologies*. 7th revised and updated ed. Ukiah, CA: Real Goods Trading Corporation. (For further technical information, call 1-707-468-9214.)[16]
- Smith, April A. and the Student Environmental Action Coalition. 1993. *Campus ecology*. Washington, DC: Planet Press. (To obtain a copy of this book, call 1-202-686-6262; the book currently costs $15.)

Tasks

This final activity is an optional capstone project to this unit, which has focused on energy. In Alternative 4 of Activity 3.1 students were asked to observe how energy is used (and wasted) at their college. They collected information on how energy is consumed at their college; how much the institution spends on electricity, heating, and cooling; the type of light fixtures in various buildings; the behaviors of students and faculty; the existence of energy conservation programs; and the decision-making and implementation structures in place to deal with energy-related decisions.

Students should now be in a good position to use this information either to commend the college on its efficient and low energy use or to make strong and well-founded arguments challenging their institution to improve on energy conservation.

If students are motivated to "walk the talk," the instructor should encourage them to act as consultants to the college and produce a report that outlines the larger problem, the specific findings at their institution, and recommendations as to how to reduce energy consumption. In order to do so, students need to:

- learn about how to organize a succinct and effective energy conservation "proposal" (providing them with a general outline may be less effective than showing them some actual reports);
- think of what additional information they might need to make a solid case;

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[16] The module author, contributors, or CCG2 have no personal interest in furthering business for Real Goods Trading Corporation. Many other suppliers for such technologies exist and students are encouraged to look for local suppliers of the materials needed to implement their suggested solutions.

- inform themselves of possible practical solutions (e.g., how many light bulbs are needed? Are there any suppliers nearby? What would this cost? How much would it save in terms of the electricity bill? How much would this reduce CO_2 emissions, etc.) (Note that using energy-efficient light bulbs is of course not the only possible change or solution to energy waste; it is used here to demonstrate what students need to think about.);
- write (and rewrite) the actual report (incl. figures, maybe graphics, etc.); and
- split up all involved tasks and work as a team.

Students should be encouraged to consult with you, the instructor, on how to write an effective report or proposal, to check in with you occasionally to discuss problems, and to employ ethical research methods,[17] but you should give them fairly free reign in this project. Students will learn more from their mistakes and successes than they will from following a path that has been conveniently paved for them.

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[17] If students interview people to prepare this report, follow your college/university's standards and requirements on conducting research with human subjects.

3 Energy Use

Student Worksheet 3.1

The following activities all deal with energy -- its use and waste -- and possibilities for reducing energy consumption. Remember that we look at energy here as one example of a resource on which we crucially depend and which links us to our environment in at least two ways: the environment is the source of this energy and also the sink for energy-related emissions. Let's begin by looking at what role energy plays in our daily lives.

Activity 3.1 Shedding Light on Your Life

Your instructor will have told you something about what energy is, how it is defined and measured, and from what sources and in what forms it comes. In this first activity, look at when and where and for what YOU use energy in your daily life. Your instructor will explain to you in more detail the options of how to do that. You can

- choose to write your personal "energy log" for one day; or
- call up your utility provider(s) and find out where your electricity comes from; or
- critically rate all the things you use in a day that need energy and judge how essential they are in your life; or finally,
- choose to take a critical look at how your college uses/saves/wastes energy (in this last case, you may lay the basis for an exciting larger project!)

In the next exercise we will look at the big picture, i.e., how energy is used in the United States. For that, you need to know something about how energy use is measured. Your instructor will provide you with several definitions.

Student Worksheet 3.2 Name:

Activity 3.2 Analyzing and Interpreting Energy Flow Diagrams

Look at the 1982 and 1995 energy flow diagrams for the USA. These diagrams show the flow of energy of various kinds and from various sources, through any intermediate conversion stages, to the sectors of the economy that consume the energy, and finally to actual work performed by the energy. The thickness of the flows represents the quantity of energy, in Quads. Take a few minutes to understand and compare them. You may want to pair up with your neighbor and explain to each other what you see and/or don't understand about the diagrams.

These diagrams are adapted from the *Annual Energy Review*, published by the U.S. Department of Energy (DOE). Note that in the 1995 diagram, the final stage of the energy use chain on the far right has been added to the diagram. The DOE used to publish such data, but stopped after 1982. These data should be considered rough estimates in that no exact statistics are available for the efficiency of energy end use.

A. Now, recall the four definitions of energy use (i.e., PEP, TPES, TFC, and ESD), and identify on the 1995 diagram where each of these four estimates is measured.

B. Depending at which stage in the diagram we measure energy, we get different indicators (PEP, TPES, TFC and ESD), and their respective amounts (in Quads) varies significantly. In the US case, which is the largest and which the smallest? Would this be the same in any country and if not, why not?

C. On the 1995 energy flow diagram, what is the main use of each of the primary forms of energy, and why?

Hydropower:

Nuclear:

Coal: ____________________

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Natural Gas: ____________________

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Oil: ____________________

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Economists use the term *elasticity* to describe the rate of change of one thing compared to the rate of change of another. Demand for oil is said to be very *inelastic with respect to price* because when the price goes up, demand does not usually fall very much.

D. Can you see any reasons in the flow diagram why the demand for oil would be so price-inelastic?

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E. What other interesting facts can you learn about the U.S. energy system from this diagram? (What about differences in efficiency; energy imports and exports; types of energy used by different sectors?)

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F. Compare the 1995 energy flow to 1982. What differences and similarities do you find?

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Student Worksheet 3.3 Name:

Activity 3.3 Crawling to Efficiency -- The "Worm Diagram"

Below are some statistics on total primary energy supply (TPES, in millions of tons of oil equivalent) and gross domestic product (GDP, in billions of constant 1985 US dollars) for various countries over the last 20-30 years. GDP measures the total value of goods and services bought and sold within the country. Note that the statistics on developed countries go back further (to 1960) than those for the less developed countries (which go back only to 1973).

	USA		Canada		Turkey		Japan		Sweden	
Year	GDP	TPES	GDP	TPES	GDP	TPES	GDP	TPES	GDP	TPES
1960	1806	1014	116	73	15	4.8	257	82	48	21
1965	2285	1220	154	99	19	7.9	402	137	62	27
1970	2714	1546	193	132	25	12	720	256	76	38
1973	3087	1723	232	153	31	24	874	321	81	39
1977	3336	1818	273	178	41	32	975	332	86	42
1980	3563	1801	301	192	42	32	1118	346	92	41
1985	4016	1771	347	193	53	39	1343	360	101	48
1990	4555	1920	399	211	70	53	1679	428	112	48

	Hungary		India		Iran		Brazil		Africa-6*	
Year	GDP	TPES	GDP	TPES	GDP	TPES	GDP	TPES	GDP	TPES
1973	14.2	21.5	128	67	154	24	136	47	27	9.4
1977	17.7	26	154	84	205	36	185	69	28	10.2
1980	19	28	164	94	125	37	216	73	31	10.7
1985	21	30.4	215	130	189	54	228	81	33	10.4
1990	21	28.6	283	179	181	73	252	97	38	12.7

Sources: (1) International Energy Agency. 1991. *Energy statistics and balances of non-OECD countries*. Paris: OECD/IEA, and (2) International Energy Agency. 1992. *Energy balances of OECD countries*. Paris: OECD/IEA. As of this writing (1996), the most recent data for OECD countries are from 1992, for non-OECD countries from 1991.

* Note on "Africa-6:" The scale of the graph paper you are provided with starts at 10 mtoe (million tons of oil equivalent). No sub-Saharan African countries supplied more than 5 mtoe in 1990, except for Nigeria, an OPEC member, and South Africa, also arguably a special case. In northern Africa, the countries of Libya, Egypt, and Algeria supplied more than 10 mtoe, but they are not representative of sub-Saharan Africa. Therefore, a composite set of data has been provided using the sum of GDP and TPES from six African countries more representative of conditions in sub-Saharan Africa: Ghana, Ivory Coast, Kenya, Zaire, Zambia, and Zimbabwe. Together, their total population is about 106 million people.

A. *Step 1*: Using Figure 24 below, plot the statistics for TPES and GDP for Iran and Japan on the log-log graph,[18] with GDP on the x-axis and TPES on the y-axis (the other eight countries have been done for you). Each country will have several points, one for each year of data. You may want to use a different colored pencil or a different marker style for each country.

B. *Step 2*: The points for each country can be interpreted in the sense of a development path, or sequence. Draw a worm-like boundary around each sequence, being sure to follow each twist and turn. What you will produce is nicknamed a "worm diagram," for obvious reasons.

C. Compare the table and the worm diagram. In what ways are these two methods of representing the same data better or worse in focusing your attention on what you feel is important here? What did you pay attention to in the table, and what sticks out in the worm diagram? So, does the way in which data are presented affect the way in which you define a problem? Please explain!

D. Now let's go back to the worm diagram. As discussed in the *Background Information* for Unit 3, there seems to be a general rule that increasing a country's GDP always requires increasing energy consumption. Are there any exceptions? What special circumstances (in time and place) might explain this break from business-as-usual? (Write down your answer below.)

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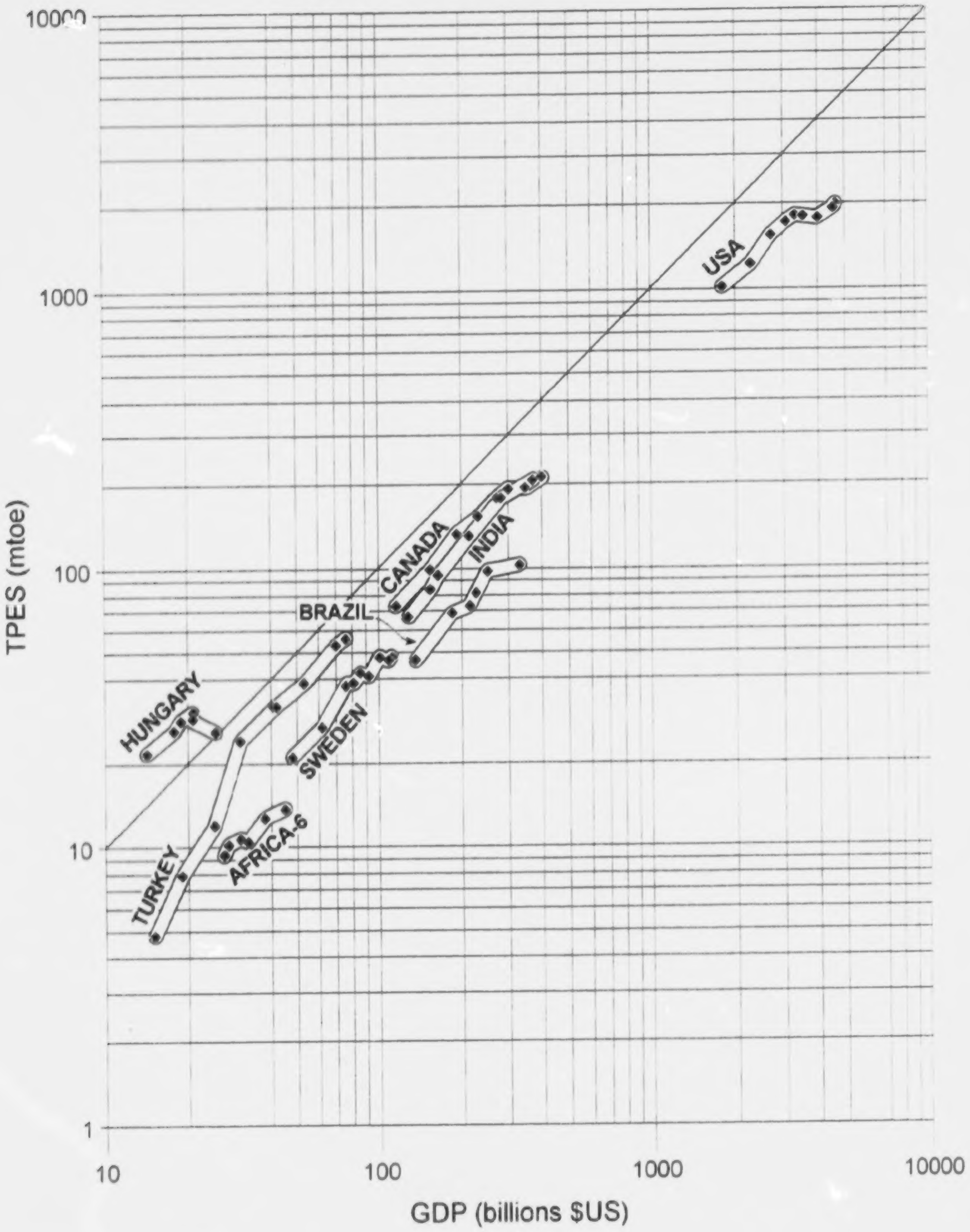
[18] Usually, semi-log paper is used to straighten out an exponential function; that is, the year would be on the x-axis, without a log scale, and the exponentially growing variable would be on the y-axis with a log scale, and the curve would come out as a straight line. In this case, both GDP and TPES are growing exponentially, so the sequences would form more or less straight lines even on regular, non-log paper. The reason why log paper is used here is that it allows a big country like the USA and a small country like Hungary to be shown on the same graph, despite the fact that the US GDP is about 100 times bigger.

Figure 24: Worm Diagram



(*Question D continued*)

E. How can you tell from the worm diagram which countries' GDP is growing fastest?

F. Economists define *energy intensity* as the ratio of energy use to GDP, i.e., TPES/GDP, and they usually measure it in *millions of tons of oil equivalent (mtoe)*/$. What does energy intensity tell us about a country?

G. How does energy intensity manifest itself on the worm diagram with reference to the 45° line? (You may think about where you'd find the greatest and lowest energy intensity in the graph.)

H. Which countries were most and least energy intensive in 1990, and why? (We will come back to this question later, after introducing the concepts of technological and structural change.)

Economists also use the notion of *income elasticity* to describe the *relationship between energy use* and *economic growth over time*. Earlier, in Activity 3.2, we introduced *price elasticity*, which describes how energy demand responds to price changes. Here were explore how energy demand responds to changes in national income. Energy demand elasticity is defined as:

$$\frac{\textit{annual percentage change in primary energy supply}}{\textit{annual percentage change in GDP}}$$

Energy demand-income elasticity tells us something about change over time, compared with energy intensity, which is a snapshot of a country's overall energy use pattern at a given point in time.

I. What does an energy elasticity of 1.0 mean? What does one of less than 1.0 mean?

J. Just by looking at the shapes of the worms, how can you tell whether a country's energy elasticity is greater or less than 1.0 between two points in time? Think of what it means to be steeper or flatter than the 45° line that connects two points in time.

K. Interpret the trends in the United States' energy elasticity since 1960. What do you think was responsible for the downturn in the 1970s and the upturn in the 1980s?

L. Summarize the differences between the two related concepts of energy elasticity and energy intensity. Think of what happens to energy intensity when elasticity is greater than or less than 1.0.

Student Worksheet 3.4 Name: ____________

Activity 3.4 What Needs to Change -- Technology or the Economy?

The worm diagrams showed that only in exceptional circumstances have countries been able to expand their economies while shrinking their energy consumption. On the other hand, they also show that energy consumption need not grow as fast as the GDP. Two factors, technological change and structural change, are primarily responsible for reducing energy intensity. *Technological change* means switching from one technology with all its inputs, machinery, and know-how to another. Frequently, it implies an improvement in the efficiency of energy-using machines, such as better gas mileage for automobiles. Technological change, however, also creates many new uses for energy so that the total amount of energy used may actually go up. *Structural change* refers to changes in the sectoral structure of the national economy as a society develops, indicating a change in where economic activities predominantly take place. Economic structure affects energy use because some economic activities produce economic value with less energy consumption than others. In this activity we will look at both types of changes in turn to understand their importance.

Technological Change

A. First, brainstorm with the other students in your class about how technological change can both increase energy efficiency and increase total energy consumption. What do the technologies that increase energy efficiency have in common? What about those that decrease it? What does that tell you about what kind of technological change is desirable if reduction of energy consumption is the goal? Use the few lines below just to take notes on your discussion.

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Now let's go back to the energy flow diagrams you looked at in Activity 3.2. On the 1995 diagram, find where primary energy is converted to electricity and where electricity is transmitted to the final consumers. Notice the large losses in energy suffered in converting primary energy to electricity and transmitting it to users.

B. Calculate the technical efficiency of the electricity conversion/transmission/distribution process for both 1982 and 1995, using the following formula: efficiency (in %) = 100 × (total energy output divided by total energy input).

C. Compare the two results from Question B. How has technical efficiency improved from 1982 to 1995? Does that surprise you?

D. Look at the Department of Energy Table 2.13 from the *US Annual Energy Review 1995* (provided by your instructor). Describe the existing potential for technological change in the home appliance sector. If you are working in groups, imagine you were a member of a panel of technology and engineering experts whose task it is to revolutionize the home appliance sector. Use the space below for taking notes on your discussion.

Structural Change

The economy of a country is usually divided into three (or four) sectors based on the stage of its economic development. The *primary* sector includes those industries that produce raw materials, including agriculture, mining, forestry, and fishing. The *secondary* sector, including all manufacturing and food processing industries, transforms those raw materials into useful goods, giving them what is sometimes called "form utility." It does not sell directly to the people. The *tertiary* sector, which comprises the retail and service industries, delivers manufactured goods to the consumers or otherwise provides some kind of good or service directly to the people. The retail industry is said to provide "place utility" to the goods produced by the secondary sector. Transportation and communication do not fit neatly into this scheme, but span all sectors: oil drilling is clearly primary; oil refining and auto or telephone manufacturing are clearly secondary, while airlines, phone service companies, and taxis are clearly tertiary. Some economists also identify a *quaternary* sector made up of information industries like education, insurance, finance, and consulting that create quite a lot of economic value but do not produce, sell, or service a physical good of any kind, and therefore tend not to use a lot of energy.

As an economy develops from the traditional or preindustrial stage to a rural, agricultural economy, then to an urban industrial economy, and finally to a postindustrial, information-based economy, the sectoral breakdown of the economy changes dramatically. *Supporting Material 3.4b* (provided by your instructor) graphically depicts the percentage of employment in different sectors in the US economy as it developed over time.

E. In your group, discuss the structural changes evident in this figure during the last 100 years. Use the space below for notes.

Manufacturing is a far more energy-intensive activity than agriculture, retail, services, or information processing, in the sense that factories tend to use more energy to produce the same dollar amount of GDP than do offices or farms (though this varies greatly by type of farm and type of factory). *Supporting Material 3.4c* (provided by your instructor) shows the energy intensity of the US economy over roughly 120 years.

F. Compare these two figures *(3.4b and 3.4c)* and discuss in your group how structural change appears to be related to energy intensity. How does technological change fit into this picture? Again, use the space below for notes you take during your discussion.

G. Revisit the worm diagram in Activity 3.3. How do the concepts of economic structure and technological efficiency help to explain the different energy intensities of countries? Give an example!

H. How might other geographic factors (e.g., resource availability, political or cultural differences, or climate) help explain some of the differences between these countries? Again, use examples if you can.

Student Worksheet 3.5 Name:

Activity 3.5 So ... What Do We Do? Three Mitigation Measures

In this exercise you will look at three ways to satisfy the energy needs of a global population that is growing in size and in wealth but doing so either with less energy or with energy that is less polluting: 1) demand-side management; 2) renewable resources; 3) lifestyle changes. Read through the first section, solve the problems, and then compare, discuss and, if necessary, correct them together with your neighbor.

Demand Side Management

Electric utilities are required by the Federal Energy Regulatory Commission (FERC) to project future electricity needs and to make sure that they will be able to supply enough power. Recently, utilities have begun to realize that instead of investing capital in building more power plants, they can invest in helping their customers reduce the amount of electricity they consume by installing more energy-efficient equipment. This is known as demand-side management (DSM), or as integrated resource planning (the term used in the Lenssen paper that you may have read). The economic benefit to customers is the ability to provide the same level of energy services at a lower cost. The advantage to the utilities is that it reduces the need to build new power plants and reduces the environmental impacts, especially fossil fuel emissions. It is estimated that since 1989, DSM programs have reduced peak summer generating requirements by 25,000 megawatts, or 5% of total US power plant capacity. In 1994 alone, US utilities spent $2.7 billion on DSM programs.

The following calculations illustrate how the energy savings multiply by working backwards through the energy flow diagram from savings in energy service demand to savings in final energy consumption and back to the savings in primary energy supply into the electricity sector.

A. **Step 1**. In the 1995 energy flow diagram, what was the efficiency, in percent, of converting energy to useful work in the residential/commercial sector? Here is how to calculate the conversion efficiency:

efficiency (in %) = 100 × output/input, with input being energy, and output useful work.

As you saw in the DOE Table, the efficiency of the country's stock of residential appliances can be improved by 14-70% by replacing older, less-efficient appliances with newer, more-efficient models.

B. **Step 2**. Let's assume conservatively that the average efficiency of electricity consumption in the residential sector could be improved by 25%. That's another way of saying: cut the energy *losses* from energy consumption to energy service demand by 25%. First, think of how much energy is lost now, then what the losses would be if they were 25% less. Write your answer below.

C. **Step 3**. Your answer to B implies the same outputs can be produced with fewer inputs. Recall how to calculate efficiency, and then figure out what the *new* efficiency of the residential/ commercial sector would be.

D. **Step 4**. Now we will start working our way back up the energy chain. Though it is not shown on the chart, the residential/commercial sector consumed 6.25 Quads of electricity in 1995. What *percentage* of residential/commercial energy came from electricity?

E. **Step 5**. Assuming that the cut in losses calculated in B applies uniformly to all energy types, what would be the reduction in electricity consumption by the residential/commercial sector?

Finally, if the electricity industry has to supply less electricity to the residential sector, it will need to use less fossil fuel, nuclear, hydropower, and renewable energy than before.

F. **Step 6**. With the improved efficiency in residential usage, how much less primary energy would have to be input to the electricity sector, given the conversion efficiency of power generation in 1995? Think first of the figures you need (all calculated before) to solve this question. To solve this problem, use the following formula: $x \times y = z$. Solve the equation for x, i.e., $x = z/y$, with x = savings in energy used by the electric utilities, y = conversion efficiency (use the answer to Activity 3.4 Question B for 1982), and z = savings in electricity produced (use the answer to question B above).

G. What insights can you draw from the six steps you just went through regarding why utility companies have been moving toward demand-side management? Why might it make economic sense for them to invest capital in homeowners' residences, e.g., in better house insulation, or more efficient water heaters, etc.?

Renewable Resources

Renewable resources are those that can be restored after consumption. Some, like solar energy, are automatically restored, while others, like wood, must be managed to ensure that they are restored. *Nonrenewable* resources, on the other hand, cannot be reused or regenerated -- at least not on a human time scale. It is true that nonrenewable fossil fuels like oil, coal, and natural gas are constantly being formed by decayed organic material, which is why they are sometimes referred to as "fossil sunlight" since the original plants required sunlight to grow. But because fossil fuels require millions of years to form, they are nonrenewable for all practical purposes. The concepts of renewability and nonrenewability apply not only to energy but to industrial materials as well -- cotton is a renewable source of fibers, whereas nylon is synthetically produced from oil or gas. In the future, sustainable energy use will have to rely quite heavily on renewable sources of energy.

One of the difficulties in measuring the amount of renewable energy use is that much of it is *noncommercial* energy; that is, the energy source itself (sun, wind, water) is not sold by one firm to another, and thus is not recorded in economic statistics. People or firms who cut their own wood, put up a windmill, or heat their own pools with a solar water heater do not buy or sell any energy, though sometimes the usage can be inferred from their purchase of renewable energy equipment. If you compare the 1995 energy flow diagram with the one for 1982, you'll see that back in 1982, estimates of the various uses of renewable energy were included. In the most recent energy flow diagram, only commercially sold energy is recorded. However, other estimates of renewable energy consumption are found in Tables 10.1, F, G, and K from the US DOE *Annual Energy Review* (*Supporting Materials 3.5a-d*). Answer the following questions based on the 1982 and 1995 energy flow diagrams and the DOE tables.

H. How much of our energy do we get from renewable sources, and how much progress has been made since 1982?

I. How much of the different kinds of renewable energy do we use? And for what types of applications?

J. Which energy end uses have not been able to take advantage of renewable energy sources in a significant way, and why do you think that is so?

K. Based on your own understanding and on the readings, what are the primary advantages of renewable energy, and what, if any, are the economic and environmental disadvantages of each kind of renewable energy?

Lifestyle Changes

A third way to reduce the energy intensity of the economy is through lifestyle or cultural change. The US way of life tends to be very energy intensive. US citizens, on average, use more energy per capita than Western European or Japanese citizens with similar GDP per capita.

L. In the space below, take some notes on why you believe that the US lifestyle tends to use more energy than the European or Japanese lifestyle. For what kinds of activities do you use commercial energy that your parents' or grandparents' generations either did not undertake at all or accomplished without using commercial energy? What lifestyle changes could you make to lower your personal energy consumption?

When you've finished taking notes, come together in groups for a discussion based on your notes; alternatively, have a panel discussion or stage a role play; you could also take polls in class on what each one of you thinks are the lifestyle changes that make most sense. Your instructor will tell you more about each of these options.

Student Worksheet 3.6

Activity 3.6 Walk the Talk! Energy Conservation on Campus

In this final activity of this unit, you return to where you started from: how is energy used at your college? The idea here is to try to *make a real difference* -- to not just talk about energy conservation, but to actually come up with a practical plan on how to do it, and to implement it, in short: walk the talk!

If your previous observations of energy use at your college showed that there is plenty of room for improvement, then you've got a case. Well ... do you? So far, you have notes, and you've learned some facts about soaring worldwide energy use, you got some skills under your belt, and you have probably lots of ideas in your head on what to do better. That is great stuff to work from, but it's not the "plan" quite yet.

Imagine you and your classmates were a team of environmental consultants that was asked to investigate how the college is doing on the "energy front," if it needed to make any changes, and if so, what exactly it would have to do. Of course, the administration is always concerned about costs, and so you are asked to include some basic cost and benefit statement in your report. So, how do you go about putting such a report together? Here are some things you could think about:

- how do you organize a succinct and effective energy conservation "audit" or "proposal?"
- what additional information might you need to make a solid case?
- how and where do you find out about possible practical solutions (e.g., how many light bulbs are needed? Are there any "able" suppliers nearby? What would this cost? How much would it save in terms of the electricity bill? How much would this reduce CO_2 emissions, etc.) (Note that using energy efficient light bulbs is of course not the only possible change or solution to energy wastage; you can make this as extensive as you think is necessary!)
- who is going to write (and rewrite) the actual report?
- do we need tables or graphics?
- who is going to be on the team with you? Who will do what? How can we make this work?
- do we need to be aware of any specific research or report writing rules?

Brainstorm together with your classmates, ask your instructor for help if you need it, form your consultant teams, and then get to it! There is lots of energy to save!

3 Energy Use

Answers to Activities

Activity 3.1 Shedding Light on Your Life

There are no specific answers to this activity; the teaching directions and the *Supporting Material* hold all the necessary information. The results of the activity will depend on the alternative chosen and the experiences that students bring to this activity.

Activity 3.2 Analyzing and Interpreting Energy Flow Diagrams

Answers to this activity are as follows:

A. Going from left to right across the 1995 energy flow diagram,

- PEP should be marked on the very left of the diagram (where the arrow is labeled 71.16) before any additions from energy imports;
- TPES should be marked after all imports have been added and all exports have been subtracted (where the arrow is labeled 95.19);
- TFC should be marked where energy enters the residential, industrial, and transport end use sectors (arrow labeled 69.26);
- ESD, finally, should be marked at the far right end of the diagram (at the arrow labeled 39.07). Note also that ESD does not include the end use losses.

B. Total Primary Energy Supply is the largest, Energy Service Demand is the smallest, with the other two measures in between.

Whether or not TPES is always the largest and ESD always the smallest portion in the flow diagram will depend largely on whether the country is a net importer or exporter of energy. Because the USA is a net importer, TPES is larger than primary energy production, but if a country is a net exporter, PEP will be larger. Because of energy losses in generating and transmitting electricity, TPES should always be larger than TFC. Likewise, TFC will always be larger than ESD because of end use losses.

C. **Hydropower**: Electricity generation; dams also provide non-energy services like irrigation, recreation, and flood control.

Nuclear: Electricity generation; the only other purpose can be military transport (nuclear submarines).

Coal: Electricity generation; coal is the cheapest, most plentiful, but also most polluting of the fossil fuels. Coal is also used for making coke for the steel industry; however, in many lesser developed countries, like China, coal is also used for steam locomotives, home heating and cooking, industrial boilers, and chemical feedstock.

Natural Gas: Industrial and residential/commercial; natural gas is relatively easily transported by pipeline but not by other means. Because it is often a by-product of oil drilling, it is relatively inexpensive. It's greatest advantage, however, is that it is the cleanest burning fuel, especially for home or commercial use.

Oil: Transportation; oil is the raw material for gasoline and diesel which the majority of motors require as fuel. Most oil power plants have been converted to coal, which is far more plentiful both domestically and worldwide. Oil is also the main input for the petrochemical industry.

D. The energy flow diagram clearly shows that there are very few substitutes for oil in the transportation sector. (With the recent development of cars that run on electricity and natural gas, this may soon change.)

E. Notice the very low efficiency of transport as compared to residential, commercial, and industrial end uses. Coal is the only energy source exported by the U.S. Electricity is used mostly be homes and offices, with the myriad of very small applications of inanimate energy, plus refrigeration and lighting. Industry, in contrast, uses primarily heat energy from burning oil and gas in larger scale applications. Hydroelectric power is imported from Quebec to New England.

F. Total Primary Energy Supply grew from 73 to 95 Quads. Oil use has risen the most, but in inflation-adjusted terms, it is cheaper today than in 1982. Still, it is surprising that more substitution away from oil has not occurred. Oil imports in both absolute and relative terms have gone up dramatically. Electricity generation has gone up substantially as the service sector has grown, computers have proliferated, and homes have gotten larger and use more appliances. In terms of total final consumption, however, industry and transport have grown much faster than residential/commercial. Renewables have made very little progress since 1982.

Activity 3.3 Crawling to Efficiency -- The "Worm Diagrams"

Answers to this activity are as follows:

A-B. Worm diagram shown on next page.

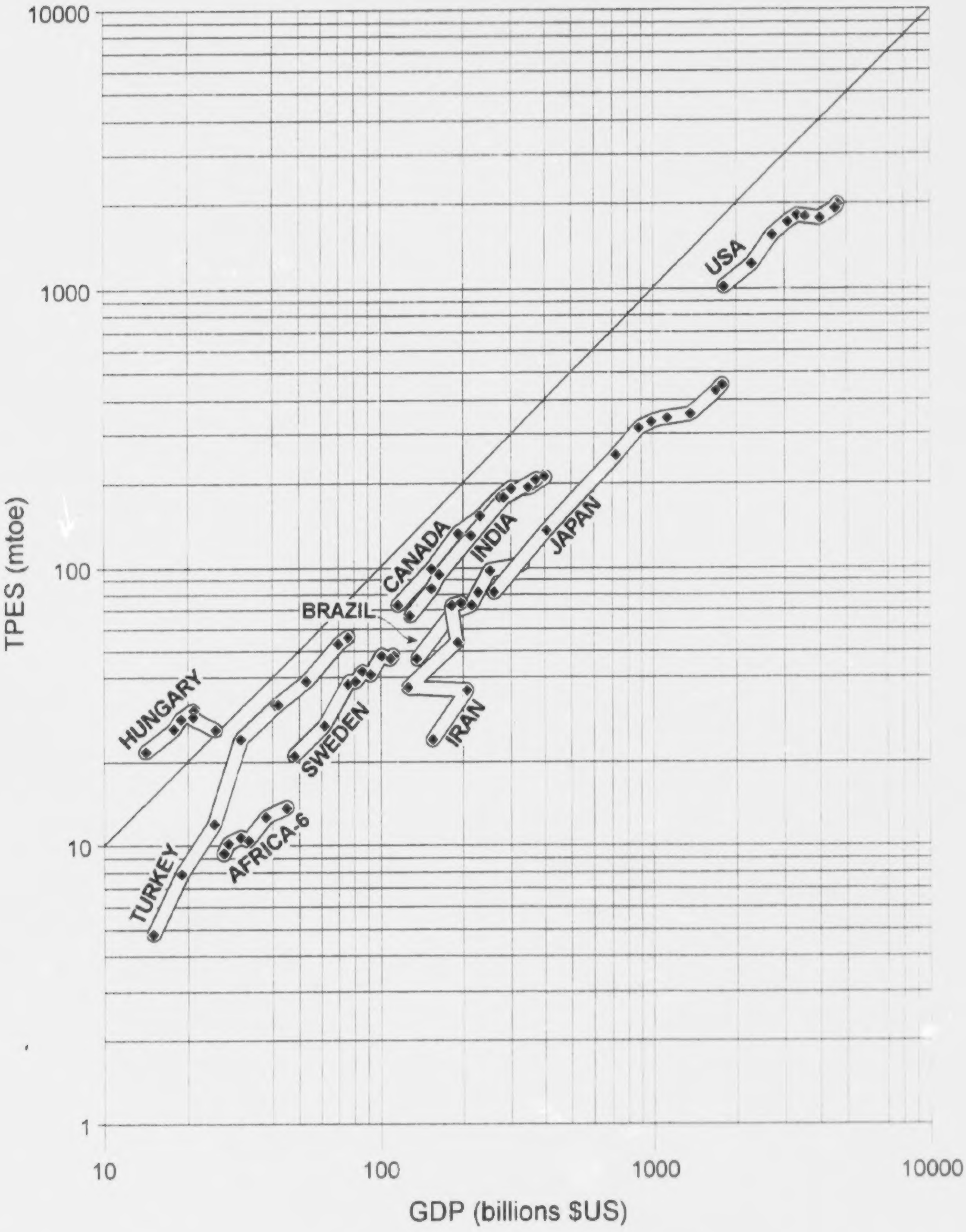
C. The table-format allows us to compare the level of energy supply and GDP at specific years within and across countries numerically whereas the worm diagram is a visual representation of the data. This has several implications: The worm diagram helps us to get an overview of the relative situations of various countries much more quickly than the table does. It is easy to see periods of enhanced or lessened efficiency in the development paths of different countries. Because of the logarithmic scales used in the worm diagram, the actual numbers can be read more easily from the table, and quantitative analysis can be performed readily on the data in the table but not from the worm diagram.

The two ways of showing the same data thus highlight different relationships and allow different analyses. While the interpretations may be the same, the two presentations can be used to stress different aspects. This may direct one's interpretation of the data in different directions.

D. Hungary, Africa-6, Sweden, USA have dips downward and to the right in their sequences. These dips mean that increases in GDP have been achieved without increasing the use of energy. Such energy-efficient changes in the development paths have different causes: Hungary was a very energy-inefficient socialist state undergoing reform in the late 1980s. Sweden has actively embraced energy efficiency. The six African countries may have substituted noncommercial energy (biomass) for commercial energy when oil prices were high in the early 1980s, or they may have conserved. Many African countries do not have the export earnings with which to generate foreign exchange to pay for imported oil. In the USA, it was mostly a market response to higher energy prices.

E. On a log graph, the horizontal distance between the beginning and the end of a worm shows percentage GDP growth over the measured time period. Turkey experienced the fastest growth, Iran the slowest.

Worm Diagram (Answer Key)



(Answers to Activity 3.3, continued)

F. Energy intensity tells us how efficiently a country creates GDP out of energy, or how much economic value they get out of each unit of energy they consume. Low intensity is generally better than high intensity, all else being equal.

G. Energy intensity is manifested in the perpendicular distance away from the 45° line. Above and to the left of the line is high intensity, while below and to the right is low intensity. In other words, the highest possible energy intensity would be at the upper left corner of the graph, and the lowest at the lower right corner.

H. In 1990 Japan was the least energy-intensive country, and Hungary was the most. Japan has no domestic sources of energy and thus prices it high and uses it very efficiently. Hungary received subsidized energy from the USSR and thus used energy, and most other factors of production, very inefficiently.

I. Elasticity of 1.0 means that GDP and energy supply are growing at the same percentage rate. Less than 1.0 means that GDP is growing faster than energy supply, which is good!

J. Steeper than 45° implies an elasticity > 1.0 because energy supply on the *y*-axis is rising faster. Flatter than 45° implies elasticity < 1.0.

K. From 1960 to 1980, there was a slightly flatter than 45° slope. GDP doubled, but TPES grew by only 78%. After the oil shocks of 1974 and 1979, the elasticity fell sharply. GDP grew but TPES stayed relatively the same. Then, from 1985 to 1990, TPES grew again as energy prices fell.

L. When elasticity is > 1.0, the energy intensity is rising, and when elasticity is < 1.0, intensity is falling.

Activity 3.4 What Needs to Change -- Technology or the Economy?

Answers to this activity are as follows:

A. Specific answers, of course, depend on students' knowledge, yet may include some of the following points:

- different or improved technologies may cut the losses of energy that occur during production, transportation, and end use;
- new technologies may replace previously energy-wasteful or previously energy-conserving (manual) technologies thus reducing or increasing total energy use, respectively;

- new or imported technologies may switch from non-renewable to renewable energy, thereby not necessarily cutting the total amount of energy used, but reducing the use of non-renewable energy sources;
- the centralization and decentralization of energy production can have both types of effects on energy efficiency (reduction of losses during transportation from central production places to peripheral users; possibility of investment in big, central, energy-efficient production plants, etc.);
- decentralization of electricity production in particular may allow more experimentation with renewable energy technologies, which means a turn away from non-renewable energy sources;
- some new technologies may not be energy efficient in the first place;
- some new and very energy-efficient technologies find such a wide acceptance and such a large array of applications that efficiency is made up for by excessive use.

B. 1995: $100 \times \underbrace{(30.42 - 20.92)}_{\text{Electricity output not shown but can be calculated as inputs minus losses}}/30.42 = 9.49/30.42 = \mathbf{31.20\%}$

1982: $100 \times 7.0/24.0 = \mathbf{29.17\%}$

C. Yes, there's been about a 7% (or, absolutely, 2 percentage point) improvement in efficiency. Students may find this a surprisingly little improvement in efficiency!

D. Students' thoughts on this question should at least include the following: The efficiency of appliances varies by age, and room for improvement also depends on the kind of appliance. In general, newer appliances are more energy efficient. Thus, the benefit of replacing an existing freezer with a state-of-the-art freezer depends on the age of the freezer being replaced. In Table 2.13, the row "Potential Efficiency Gain" is the percentage difference between the best available appliance and the average appliance in the residential stock. It ranges from an average of a 70% increase for home freezers to a 14% gain for gas furnaces. Thus, freezer technology has improved much more than furnace technology recently.

E. Students' discussion should include the following observations: The proportion of the primary sector (agriculture, mining, forestry, and fishing) of the total national economy has fallen steadily and now employs less than 5% of the workforce, despite the fact that we produce more food, coal, wood, and fish than ever before. The manufacturing sector rose gradually until 1920 and then flattened out, though with a major dip during the Great Depression. The retail and service sector has come to dominate our economy in terms of jobs.

The other graph shows the three economic sectors over roughly the same years, but looks at the total value of their output rather than their percentage shares. It shows quite clearly that even though manufacturing has peaked in relative terms, its absolute output is still rising exponentially. The graph also illustrates how little economic value is generated by raw materials.

Manufacturing is a far more energy-intensive activity than agriculture, retail, services, or information processing, in the sense that factories tend to use more energy to produce the same dollar amount of GDP than do offices or farms (though this varies greatly by type of farm and type of factory). The figure in *Supporting Material 3.4c* shows the energy intensity of the US economy over roughly the same period as the structural change in figure in *Supporting Material 3.4b*.

F. The group discussion should bring out the following points: The rise in energy intensity from 1880 to 1920 could be attributed to the rise in the manufacturing sector, which tends to use a lot more energy than other sectors. The decline since 1920 could be due to the rising dominance of the service sector, which uses less energy to create equal value. For instance, it generally takes more energy to produce a thing (secondary sector) than to sell it or fix it or use it (tertiary sector). However, the rise in intensity from 1880-1920 on the graph in *Supporting Material 3.4b* is also due to the substitution of coal -- a commercial energy product -- for wood, a noncommercial (free and uncounted) source of energy. The three diamonds in the diagram show energy intensity estimates including firewood, and you can see that the intensity rise from 1880-1920 is not as great as the commercial energy intensity suggests.

G. As mentioned previously, different sectors of the economy use different *amounts* of energy and different *sources* of energy. The former (amounts) is one simple way of relating energy use to economic structure, the latter (sources) is a way of relating technical efficiency to economic structure. Amount of energy, source of energy, and economic structure thus are connected as follows: At any given point on a country's development path, certain sectors in its economic structure play more or less important roles. Generally, each sector can be said to be more or less energy intensive. (Remind students that we said previously that manufacturing is far more energy intensive than agriculture, retail, services, or information processing in that factories tend to use more energy to produce the same dollar amount of GDP than do offices or farms.)

Depending on the technological development of this country, energy production, transformation, transportation, and use in each sector are more or less energy efficient.

Example: Turkey and Hungary are both middle-income countries that still have quite a substantial part of their workforces in the primary and secondary sectors. That may help explain their high energy intensities. Canada and Sweden have similar development levels, so technical efficiency (and underlying value-determined choices), most likely spurred on by higher energy prices in Sweden, might explain the difference in their energy intensities.

H. The list of factors may include the following:

- Less developed countries probably use a lot of crop waste and fuelwood -- noncommercial biomass energy;
- Canada and the US, for example, are rich in energy resources, whereas Japan is not;.
- Canada, the US, and China are large and geographically spread out countries, whereas Japan is rather compact; thus shape and size affect the proportional amount of energy going into transportation;
- Iran's energy intensity bounces all over the graph as oil prices affect its GNP which is derived largely from oil exports. (Notice in the table given at the beginning of Activity 3.3 how Iran's TPES is rising steadily while its GDP is quite variable.)
- countries in colder climates may use more energy, but they might also be driven to use energy more efficiently because of a greater need for it;
- countries may have a "conservationist" kind of culture, an attitude toward using the earth's resources more mindfully (using less, more efficiently, and relying more upon renewables);
- the leaders of countries may or may not have the inclination to pursue and power to implement, monitor, and enforce more energy-conserving economic and technological policies.

Activity 3.5 So ... What Do We Do? Three Mitigation Measures

Answers to this activity are as follows:

A. 100 × 14.42/17.98 = **80.2%**

B. The diagram shows 3.55 Quads lost. A 25% cut in losses would be 3.55 × 0.25 = **0.8875** fewer Quads lost. In other words, the losses would fall from **3.55** Quads to **2.66** Quads.

C. The new efficiency would be 100 × 14.42 ÷ (17.98 - 0.8875) = 100 × 14.42 ÷ 17.09 = **84.4%**

D. 100 × 6.25/17.98 = **34.8%**

E. 0.348 × 0.8875 = **0.308 Quads**. 0.308 Quads less energy will be consumed by the residential sector.

F. $x \times 0.312 = 0.308$
$x = 0.308/0.312$
$x = \mathbf{0.989}$ 0.989 Quads less energy would be used by the electric utilities.

G. From the previous calculations, it follows that 0.308 Quads less electricity used by the residential sector translates into almost 1 Quad less of coal or nuclear power. If coal is the energy source, this means savings of almost 48 million tons of coal, over 5% of the US's coal consumption in 1995. Depending on coal quality (with its economic and environmental implications) and thus coal prices, this might be a tremendous savings for utilities companies.

H. The 1982 flow diagram shows 6.2 Quads of renewable energy production, whereas Table 10.1 estimates 6.879 Quads for 1995. This demonstrates that little progress has been made.

I. Biofuels were second with 2.941 Quads of wood, methanol for a gasoline additive, municipal waste for waste-to-energy power plants (i.e., trash, derived mostly from paper, which is derived from wood). Hydropower was first with 3.462 Quads (3.309 + 0.153). Together, biofuels and hydro account for 93% of renewable energy use in the US. Solar energy use is, so far, a pittance.

Electric utilities use half of all renewable energy, while industry uses 38%. DOE Table F shows that most solar thermal energy is used for residential pool heating. DOE Table K shows that most solar photovoltaic energy is used for remote power generation and remote communications relay stations. DOE Table G shows an exponential growth in photovoltaic shipments.

J. Transportation uses very little renewable energy, 0.105 Quads. The reason is that the large majority of motors run only on petroleum-based fuels. Once electric or biogas vehicles become more prevalent, we will probably see a shift in the importance of renewables in transportation.

K. Students' answers should include some of the following arguments:

Advantages of renewable energy:

- Large supply of biofuels and hydropower if managed properly;
- Infinite supply of solar energy;
- Low-polluting or non-polluting except for wood and also for equipment manufacture;
- Excellent for use in remote locations where tying into the electricity transmission network is expensive; and
- In the long run cheaper taking socioeconomic and environmental costs into account.

Disadvantages of renewable energy:

- Solar is currently expensive, though the cost is dropping fast;
- Solar is dangerous -- people can get injured falling off their roofs (no kidding);
- Current solar technology uses toxic heavy metals in the solar cells for which we face a disposal problem;
- Hydropower is capital intensive;

- Hydropower production often implies flooding of important agricultural or wilderness areas or regions of great importance to indigenous peoples;
- Hydropower disrupts river ecosystems and sediment flow;
- Wood smoke is highly polluting;
- Ethanol would take away from food production -- not a problem in the US, but a major tradeoff worldwide.

L. Students' answers may include any of the following points:

- USA vs. Japan or Europe: The US has larger, less well-insulated (wood) homes, more private autos (also more cars per household), dispersed suburbs, unpopular or nonexistent mass transit, more private swimming pools, larger backyards (which Americans keep mowed), and with its rather individualistic culture maybe less of a "common good"-oriented, conservationist attitude, etc.
- Today vs. 50 years ago: More private autos, more air travel, more machines of every kind to replace manual labor in the home, more specialization, more material possessions of all kinds, more plastic that is made from petroleum, more of a "throw-away"-attitude, resulting in the perpetual need for more new things.
- What one can do (list can be extended almost indefinitely): reduce, reuse, recycle, bicycle, walk, drive less, buy smaller and more fuel-efficient car, take mass transit, car pool, hang laundry to dry, set thermostat at lower temperature, get programmable thermostat, insulate, install efficient compact fluorescent light bulbs, turn off light when you leave room, etc.

Activity 3.6 Walk the Talk! Energy Conservation on Campus

There are no specific answers to this questions. Answers will depend in part on the energy-use situation at the institution, student ambition in this project, the length of time available for the activity, and possibilities for reduction of energy use.

4 Only One Earth: From Controversy to Constructive Understanding

Background Information

Controversial Viewpoints Once Again: Some Background to the Readings

This unit contains some contextual information and commentary on six readings (beyond this *Background Information* text) suggested to complement this unit. You may read all of the suggested supplementary readings, but his background information will give you a taste of all of them. The readings highlight aspects of the population-environment debate. Now that you have a basic understanding of the underlying population and resource consumption issues, you may find it easier to follow this debate critically and form your own opinion.

The first reading is co-authored by Paul Ehrlich, an ecologist, who has been the leading voice calling for zero population growth since the 1970s. He is one of the few scientists who has broken through to the general public with books like *The population bomb* (1968) and appearances on the Tonight Show. The paper by Ehrlich and Holdren (1971) considers pollution to grow at least proportionally with population. This paper is squarely in the neo-Malthusian camp and is an early version of the IPAT formula (or environmental Impact equals Population times Affluence times Technology).

Barry Commoner, an environmental biologist, also transcends academics, having run for President in 1976. The second reading, Commoner, Corr, and Stamler's (1971) response to Ehrlich places the blame for pollution squarely at the feet of inappropriate modern technology. Though an avid environmentalist, Commoner is more of an optimist than Ehrlich and Holdren. Although the Ehrlich and Holdren and Commoner papers are somewhat dated, they are written with a clarity and purpose that is rare in today's more specialized and cautious scientific writings, and their logic is no less valid now than when they were written.

Paul Harrison's (1994) paper starts out as a published response to criticism of a paper he wrote in the *Amicus Journal.* The first two and a half pages give you a pretty good idea of the strong feelings among the different schools of thought in the population-environment debate. His paper then forges on "Towards a post-Malthusian human ecology." By "post-Malthusian" he seems to mean moving beyond labels and black-and-white interpretations. Harrison tries to show that many competing viewpoints are actually compatible with the I=PCT formula (Impact equals Population times Consumption times Technology), when properly interpreted. He brings many schools of thought together by saying that, yes, there are planetary limits (Malthusian, pessimist schools), and yes, humans can adapt to those limits (Boserupian, optimist schools), but the crucial limits are those of our *adaptability* (mediating schools). He also presents a well-reasoned approach to (and defense of) the I=PCT formula. Thus, while he is purportedly working toward a unified theory of population-environment relationships, he is clearly coming to that task from the multiplicative school of thought (which sees population variables such as growth, size, density, and distribution interacting in a multiplicative way with other factors such as consumption and technology).

The fourth paper, by Meadows, Meadows, and Randers (1993) is the *Executive summary* of *Beyond the Limits* (1992), the sequel to *The Limits to Growth* (1972). Like its precursor, *Beyond the Limits* represents the systems dynamics school of thought and has generally been grouped in the pessimistic, neo-Malthusian, multiplicative camps. The authors, however, have taken great pains to point out that the overshoot and collapse (i.e., doomsday) scenario is only one of several possible futures. As you read this paper, think carefully about what the authors say is necessary to avert such a future. Also pay attention to what the systems approach adds to the thinking about the population-environment nexus that goes beyond the basic I=PCT case.

The paper by Julian Simon (1983), "Life on earth is getting better, not worse," is the quintessential optimist's point of view (see Unit 1). As such, it stands in marked contrast to the others, but especially to the Meadows et al. and Ehrlich and Holdren readings. Not only does Simon think that population is inconsequential in terms of the environment, he also disagrees with the basic premise that current environmental problems are in essence any different from past environmental problems before and during the Industrial Revolution.

The final suggested reading is the first chapter of the *1992 World Development Report (WDR)* by the World Bank, which was entirely dedicated to the theme of development and the environment. The Bank is the world's largest international development agency.[19] It was formed by the more developed countries with the mandate to alleviate poverty in less developed countries (although other motivations certainly play a role too). Its primary tools for alleviating poverty are technical assistance and lending money for poverty-fighting investment projects. Increasingly the World Bank is putting emphasis on helping (and in some cases requiring) countries to reform their economies in the direction of free-market capitalism.

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[19] There are two other reasons for including the *WDR* reading in this set. First, the World Bank has access to an enormous amount of data from countries around the world, which is reflected in the WDR chapter. Second, the WDR emphasizes development, which is otherwise hardly addressed in this module. Development is the context for the demographic transition and for economic growth. The rudimentary discussion of productivity in Unit 3 does not begin to do justice to the multidimensional process of development, which is beyond the scope of this module. The WDR chapter, therefore, is useful for providing background on development as it relates to population and energy.

The World Bank has been criticized for being late and half-hearted in addressing environmental issues; it has even been accused of being the agent of environmental decay by lending money for large-scale projects like Amazonian roads and Chinese coal power plants. Not until 1987 did the Bank even set up an Environmental Department. The *WDR* documents their internal response to those charges, timed to coincide with the 1992 Rio Earth Summit. The Bank's environmental philosophy is laid out in the following quote from the Foreword to the document, written by Bank President Lewis Preston (p. iii):

> The Report argues that continued, and even accelerated, economic and human development *is* sustainable and can be consistent with *improving* environmental conditions, but that will require a . . . twofold strategy. First, the positive ("win-win") links between efficient income growth and the environment need to be aggressively exploited. . . . Second, strong policies and institutions need to be put in place which cause decision makers -- corporations, households, farmers, and governments -- to adopt less-damaging forms of behavior.
>
> Where tradeoffs exist between income growth and environmental quality, the Report argues for a careful assessment of the costs and benefits of alternative policies, taking account of uncertainties and irreversibilities that may be associated with ecological processes. Some would prefer a more absolute approach to protection, but for policy makers with scarce resources seeking to raise the well-being of their citizens in an environmentally responsible manner, it is essential that tradeoffs be clarified in a rational manner and cost-effective policies designed. The Report demonstrates that much damage takes place with little or no benefit in the form of increased income. . . .

This lengthy quote illuminates the philosophy behind the reading: it is one economically oriented institution's carefully crafted version of the "global change" paradigm (see Unit 1). The "win-win" notion is the key here -- that economic growth and environmental improvement can go hand in hand. When they conflict, however, the wishes of the Bank's clients -- that is, the *governments* of the less-developed countries -- make clear their concern for raising the economic well-being of their citizens. Yet the wishes of the Bank's sponsors -- the developed countries -- are also clearly evident in Preston's emphasis on open, free-market economic reforms. Whereas Ehrlich blames pollution mostly on population and Commoner blames it mostly on technology, the World Bank attributes much of pollution to bad economic policy, such as policies that encourage overuse of natural resources (e.g., subsidies for energy and logging) or closed trade and investment policies that discourage innovation and diffusion. Reforming Third World economies along these lines, of course, translates into technology sales from the First World to the Third World. Thus, technology transfers, like many other suggested remedies, may wed economic self-interest with ecological sense, and the World Bank has invited all observers to critically assess whether this marriage is beneficial for lenders, borrowers, and the environment.

Conclusion

These six papers represent not only different viewpoints but also different disciplinary backgrounds. Ehrlich and Commoner are biologists; Meadows, Randers, Simon, and the World Bank are all from economics and management backgrounds; Harrison hails from political science. Clearly, similar academic backgrounds do not guarantee similar conclusions. Indeed, more importantly, they contribute essential factual as well as ideological aspects to this very complex human-environment relationship, all of which are legitimate and valuable. It may be time to stop thinking of the continuing population-environment debate as a controversy and begin to bank on these various perspectives as necessary contributions to an emerging new paradigm -- one that appreciates all of the following:

- environmental health;
- social well-being;
- global connections among all environmental spheres and all nations despite cultural and political differences;
- technological ingenuity side by side with human fallibility; and
- the inseparability of humans from the environment.

Global environmental change has the potential to widen the gap between rich and poor, North and South even further. It also has the potential to make us realize that there is only one earth and that we inhabit it together, we alter it together, and together we can deal effectively with the impacts. Which will it be?

4

Only One Earth: From Controversy to Constructive Understanding

Instructor's Guide to Activities

Goal

The activities associated with Unit 4 are capstone activities involving synthesis, reading comprehension, and critical thinking. They are an opportunity for students to integrate the knowledge gained in previous activities with new information gained from reading various viewpoints about the relationships between population growth, consumption, and technology, and the level of environmental degradation.

Learning Outcomes

After completing the activities associated with this unit, students should be able to:

- synthesize data gathered previously to make generalizations about population, affluence, technological development, and environmental issues in various countries;
- work in teams with other students to pool information on a group of countries;
- critically evaluate selected readings related to population and environment;
- compare and contrast how the concepts and explanations from different viewpoints would or would not apply to a group of countries; and
- evaluate the extent to which population growth, level of affluence, or level of technological development is the controlling factor in determining the level of pollution/environmental degradation.

Choice of Activities

It is neither necessary nor feasible in most cases to complete all activities in this unit. Select activities that are most appropriate for your classroom setting and that cover a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit contains the following activities:

4.1 IPAT in Action	-- Quantitative exercise using IPAT
4.2 Same World, Different World Views	-- Critical text reading, class debate
4.3 Regional Case Studies	-- Team research and oral presentation
4.4 Final Paper: Synthesis and Geographic Differentiation	-- Module synthesis and final term paper

Suggested Readings

The following readings are suggested to accompany the activities for this unit. Choose those activities that are most appropriate for the activities you select and those most adequate for the skill level of your students.

- Unit 4: Only One Earth: From Controversy to Constructive Understanding
  The background information to Unit 4 (all students should read)
- Ehrlich, Paul and John P. Holden. 1971. Impact of population growth. *Science* 71: 1212-1217. Reprinted in *Taking sides: Clashing views on controversial environmental issues*, 5th ed. (1993), Theodore Goldfarb, ed., 66-75. Guilford, CT: Dushkin Publishing Group.
- Commoner, Barry, Michael Corr, and Paul J. Stamler. 1971. The causes of pollution. *Environment* (April). Reprinted in *Taking sides: Clashing views on controversial environmental issues*, 5th ed. (1993), Theodore Goldfarb, ed., 76-87. Guilford, CT: Dushkin Publishing Group.
- Harrison, Paul. 1994. Towards a post-Malthusian human ecology. *Human Ecology Review* 1: 265-276.
- Meadows, Donella H., Meadows, Dennis L., and Jorgen Randers. 1993. Beyond the limits: An executive summary. *Bulletin of Science, Technology, and Society* 13: 3-14.
- Simon, Julian. 1983. Life on earth is getting better, not worse. *The Futurist*. August 1983. Reprinted in *Taking Sides: Clashing views on controversial environmental issues*, 5th ed. (1993), Theodore Goldfarb, ed., 326-331. Guildford, CT: Dushkin Publishing Group.
- The World Bank. 1992. *World development report 1992: Development and the environment*. Oxford: Oxford University Press. Chapter 1 ("Development and the environment: A false dichotomy"), and Figure 4 ("Environmental indicators at different country income levels") from the Executive Summary. (provided)

Additional References and Data Sources

Anonymous. 1992. A greener Bank. *The Economist* May 23, 79-80. Reprinted in *Third World 94/95*, R.J. Griffiths, ed., 206-207. Guilford, CT: Dushkin Publishing Group. (There have been numerous critiques of the World Bank's environmental policies in general and their *1992 World development report* in particular. The article summarizes the *Report* and some of the reactions to it.)

Bongaarts, John. 1994. Can the growing human population feed itself? *Scientific American* 270, 3 (March): 36-42.

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EPA Journal. 1990. Special issue on population and the environment. 16, 4 (July/August).

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Pulliam, H.R. and H.H. Haddad. 1994. Human population growth and the carrying capacity concept. *Bulletin of the Ecological Society of America* 75, 3 (September): 141-157.

Rand McNally. 1995. *World facts and maps*. Chicago, IL: Rand McNally and Co.

United Nations Population Fund (UNFPA). 1991. *Population, resources and the environment: The critical challenges*. New York: United Nations Population Fund. (Researched and drafted by Norman Myers)

United Nations Environment Programme (UNEP). *Environmental data report*. London: GEMS Monitoring and Assessment Research Center. (Choose most recent edition available at your institution)

World Resources Institute. 1995. *World resources 1994-1995*. Washington, DC: World Resources Institute.

Young, John E. 1992. *Mining the earth*. World Watch paper # 109. Washington, DC: World Watch Institute.

Preparation for Activities 4.2 - 4.4

In Activities 4.2 through 4.4, students will be organized into groups. (Number of groups and group size will depend on your class size.) Each group of students will deal in these three activities with six countries that have been grouped to represent regions, different levels of population growth, population policies, and countries representative of global change issues. Examples of these groups are listed on the following page.

For example:

a. Nauru
Malaysia
Madagascar
Sri Lanka
Indonesia
Papua New Guinea

b. Argentina
Cuba
Peru
Bolivia
Haiti
Mexico

c. Mozambique
Zimbabwe
Kenya
Egypt
Côte d'Ivoire
Rwanda

d. Azerbaijan
Pakistan
Iran
Afghanistan
India
China

e. Thailand
Viet Nam
Nepal
Bangladesh
Myanmar
Kampuchea

f. Kazakhstan
Turkey
Iraq
Yemen
Uzbekistan
Jordan

g. Canada
France
Denmark
Germany
Belgium
Italy

h. Japan
South Korea
Taiwan (R.O.C.)
Singapore
Israel
Australia

Note that the following activities might take less time and be more meaningful if students have been assigned to these countries early on in the module. By now students will already have gained some knowledge and, to some extent, will have "identified" with the problems in their particular country. This might make the discussions deeper and more engaged.

To complete the activities successfully, this prior knowledge is not required, however. Make the decision in light of the larger purpose and themes of your course.

Activity 4.1 IPAT in Action

Goals

Students put the IPAT formula to work, applying it to a longitudinal analysis of gasoline usage over time in the U.S. and to a cross-sectional analysis of emissions from coal burning in the U.S. and China.

Skills

✔ applying simple math skills (multiplication) to calculating environmental impact
✔ using IPAT for longitudinal and cross-sectional comparisons

Material Requirements

- *Student Worksheet 4.1* (provided)
- *Supporting Material 4.1a & b* (provided)
- calculator

Time Requirements

15 minutes

Tasks

Students apply the IPAT formula to two different examples. The first looks at gasoline usage in the United States between 1960 and 1995. Does technological improvement prevent total gasoline consumption from rising as it should with an increase in population and affluence? The second example compares China and the US Which country produces more coal-related emissions from power plants? Does China's large population match America's higher per capita consumption levels? And what about the technology differential?

All data are provided for the students. Students work through the much simplified calculations to compute total gasoline consumption and total coal consumption and their related emissions. This activity illustrates the fact that fossil fuels have more than one type of environmental impact, and some impacts go up while others go down. CO_2 emissions, for instance, are strictly proportional to total coal and total gasoline, but sulfur oxides and nitrogen oxides can be controlled by optional technologies.

Population, affluence, and technology are measured here in quite different units, which when multiplied with each other cancel out to give an answer in the proper units for impact, e.g., total tons of coal or sulfur dioxide, and so on. Instructors should take some time to show students how the different units multiply through and cancel out. Working with different units is a valuable skill for students to master, one they need for many different tasks.

The data in this activity come from a wide variety of sources, not all of which are consistent with each other. Great effort was taken to use real data for the inputs to this activity and to make sure that the final impacts work out to be as close as possible to published totals -- when in fact published totals are available. Data for population, consumption per capita, number of cars, miles per gallon, etc. are exact. Some data, such as the average sulfur content of raw coal used for U.S. power plants, is not published in the form needed here. The average sulfur content after coal washing is published, but for this activity the raw coal sulfur content is preferred. In cases such as these, the assumed sulfur content was *calibrated* so that the final answer is equal to the published figure of 12.6 million tons of SO_2. Also, the published data used to calculate gasoline consumption is not fully compatible with the published data on US carbon emissions from motor gasoline. There are some discrepancies regarding household vehicles vs. all vehicles, and the inclusion of minivans and trucks, and so on. For the most part, however, the data in this activity are real.

Activity 4.2 Same World, Different World Views

Goals

Students learn to sharpen their debating skills, to sort through competing arguments, and to see the many sides of the population-environment controversy.

Skills

✓ reading comprehension
✓ critical thinking
✓ group discussion (listening, arguing, taking notes, etc.)
✓ synthesizing viewpoints and accompanying major arguments
✓ identification with role and presentation in front of an "opinionated audience"

Material Requirements

- *Student Worksheet 4.2* (provided)
- *Supporting Material 4.2* (provided)
- Subset of suggested readings

Time Requirements

Several hours for reading the assigned articles outside of class.
One hour in class for preparing arguments and holding the debate.

Tasks

A great way to introduce this activity is to provide some statistics about the toll that the average, middle-class American will take on the environment during his or her lifetime. A good source for this information is Carol Madigan's 1995 book *Life's big instruction book: The almanac of indispensable information*. You can also use *Supporting Material 4.2* to introduce the activity.

The readings can be grouped together or contrasted with each other in several different ways. The instructor has a great deal of flexibility in organizing a structured debate along several different lines, depending on the course's focus and the instructor's and students' interests.

The first debate could focus on "What is the dominant cause of environmental degradation?" Is it population growth (Ehrlich and Holdren 1971), technology (Commoner et al. 1971), or government policy (World Bank 1992)? A fourth option would be to include the Meadows (1993) paper to represent the point of view that it is not one particular factor or another but the delays (time lags) in the system that prevent humankind from slowing the system down in time. The instructor can decide how many viewpoints should be expressed in this debate.

A second debate could center on optimism or pessimism. In particular, a daunting question to guide the debate could be: "Is it likely that the world will be able to avoid a global population-environment-resource crisis?" To set the parameters of the debate, the professor should lead a pre-debate discussion on what constitutes the pessimistic scenario: is it defined as a global overshoot and collapse scenario, a regional population die-off, a dramatic loss of other species but not of humans, or simply a long-term economic crash stemming from population/resource issues. You may begin the debate with each side being required to take an either-or stance, but ask them to work toward a compromise position at the end. This will lead to a greater exploration of ideas and ensure eventual resolution. To accomplish this, it may be better to choose a less catastrophic definition of the pessimistic scenario so that students are more likely to be evenly divided on the issue than they would be if they had to defend an extreme definition of the crisis. The debriefing after the debate could then center on the middle ground, and what is the most likely future course of the human economy on planet Earth. The optimistic side can draw on the papers by Simon (1983) and Commoner et al. (1971), while the pessimistic side will find plenty of ammunition in the papers by Ehrlich and Holdren (1971) and Meadows et al. (1993). Harrison (1994) calls himself a *conditional optimist*, and if the instructor so chooses, it could be set up as a three-way debate. You may choose instead to introduce Harrison's views in the post-debate discussions.

A third debate could contrast the 1970s *Limits to Growth* global paradigm and the 1990s *global change* paradigm discussed in the *Background Information* in Unit 1. The computer model in the Meadows et al. (1993) paper is *the* defining exhibit of the *Limits to growth* global thinking, although the 20 years later sequel that the students will read -- the Executive Summary of *Beyond the Limits* -- takes great pains to show that technology and markets (two linchpins of the global change paradigm) are included in the model and do hold out some hope. The World Bank (1992) paper represents the view that the economy and the environment -- and poor and rich countries -- can all benefit from technology development and transfer. The paper by Harrison (1994) is also in the forefront of the global change movement, but does not offer so clear of a contrast in the evolution of global thought.

A final note on possible debate topics: The more specific your debate question, the easier it may be to get students into it. You may go back to the starter activity questions and reintroduce a question you discussed at the beginning of this module (see Activity 1.1). After all that students have learned, see how their thinking on the topic has or has not changed. Get them to reflect on their own thinking (self-reflective thinking).

Activity 4.3 Regional Case Studies

Goals

In this activity, students apply the concepts learned in this module to summarize the population-energy-environment situation in a geographical region in the Third World.

Skills

- ✓ data gathering
- ✓ team work (collaboration, cooperation, task devising and completion, accountability, etc.)
- ✓ group discussion (note taking, arguing, listening, summarizing, synthesizing, etc.)
- ✓ common class presentation (logical and clear organization and presentation of diverse information, use of visual aids, inclusivity and balance of group members)

Material Requirements

- *Student Worksheet 4.3* (provided)
- *Supporting Material 4.3* (provided)
- Access to various data sources on population, the state of the environment, economic activity, and level of technological development (see *Additional References* mentioned above and *Appendix C: Data Sources for this Module*)
- Suggested readings used in Activity 4.2

Time Requirements

5-10 hours outside of class
15 minutes per region in class

Tasks

In this activity, each group of students must clearly and convincingly present the environmental/population/energy situation of their region/six countries to the rest of the class, using quantitative data, the arguments heard in Activity 4.2, and concepts developed earlier in this module.

To organize themselves, the students representing each country group meet outside class and discuss a step-by-step work plan of how to prepare the class presentation. For example:

- Students will have to agree on one or more adequate variables (indicators) for each category. This will be based on knowledge gained in earlier activities of this module, and on the data offered in the various sources.
- They will need to acquire information on the state of the environment, population, the economy, and the level of technological development for six countries. This information should be quantitative and possibly include two or more points in time (include narratives

only if time permits and students have dealt with these countries since the beginning of the module).

- Once students have gathered the necessary information and compiled the worksheet (*Supporting Material 4.3*), they should consider where the countries would fit in the demographic transition model, how the countries are changing (in all categories), how fast they are changing, and why they are changing.
- Students should check their first answers against the arguments presented in the readings and reiterated in the class discussion in Activity 4.2.
- The country teams then have to agree on ways to convey and display the gathered information and arguments about the region's/countries' state of environment and development to the class. This will include writing up the arguments, creating tables and visuals, and presenting the material to the class.

Each group of students makes a 10-15 minute presentation to the class (depends on number of country groups and available time). The listening students should take notes on the general situation in the region presented. The presenting group should come to some concluding assessment of the population-environment situation, including which of the viewpoints in the readings seems to hold the best explanation and remedial policy for their region.

Activity 4.4 Final Paper: Synthesis and Geographic Differentiation

Goals

Students will write a term paper synthesizing what they have learned throughout the module about how population and energy use affect the environment.

Skills

- ✓ synthesizing conceptual and factual understanding on the IPAT relationship
- ✓ recognition and explanation of regional differences in this relationship
- ✓ analytical thinking
- ✓ essay writing (clear, logical, rich, well-argued and well-written)

Material Requirements

- *Student Worksheet 4.4* (provided)
- Notes from Activity 4.2 and 4.3
- Alternatively: suggested readings and otherwise acquired knowledge about regional differences in population, affluence, technology and the environment

Time Requirements

1 week

Tasks

Students should write a final paper of 5-10 pages (depending on the weight you wish to assign this activity) in which they synthesize information from the presentations and readings (of Activity 4.3 or similar information gained elsewhere). The goal is to develop written arguments regarding the relationships between population, affluence, technology, and the throughput of energy-related emissions and pollution to the environment. Relying on their notes on different regions presented in class, students should include examples to demonstrate how these factors vary from one region of the world to another (knowledge gained earlier in this module about the situation in developed countries may also be re-introduced here).

The instructor may ask students to orient their papers toward the larger themes of the course; e.g., in a *policy-oriented course*, students could be asked to end their essay with region-specific policy recommendations, or a discussion of whether global/regional policies can meet the needs and particular situations of individual countries; in *development-* or *technology-oriented courses*, students may be asked to discuss to what extent developmental/ technological solutions appear to be viable and promising in a region of their choice; in a *human/cultural geography course*, students may discuss how cultural differences and preferences may affect the choice and acceptability of any proposed policy; and so forth.

4 Only One Earth: From Controversy to Constructive Understanding

Student Worksheet 4.1

In this final part of the population-energy-environment module, you will get the opportunity to put all the pieces and arguments together and to apply the concepts and knowledge you have gained in earlier activities. Before you begin with the activities, make sure you have chosen to be in one of the "country groups" that your instructor offered. You may have already dealt with one or more of the six countries in each group and are now ready to apply all your knowledge to them in the remainder of these activities.

Activity 4.1 IPAT in Action

The IPAT formula has been mentioned repeatedly throughout this module. It is the centerpiece of the multiplicative school of thought on the relationship between population and the environment. In its basic form, it says that environmental impact (I) is equal to population (P) times affluence (A) times technology (T). Affluence is usually measured in terms of the amount of consumption per capita of some good, which prompts some researchers to substitute the term consumption (C) for affluence. Here, consumption and affluence are considered interchangeable.

The IPAT formula is one way of estimating material throughput, that is, the flow of raw materials from their sources in the natural environment, through the human economy, and back into the natural environment which functions also as a sink for waste materials. In this activity, we will distinguish between the input part of throughput ("Resource Throughput"), and the output part of throughput, that is, emissions or pollution ("Impact").

The idea behind the P × A part of the formula is simple: the more people there are, and the more each person consumes, the more total resources must be produced and the more waste is generated. Ten persons consuming one ton each creates the same amount of throughput as five persons consuming two tons each or 20 persons consuming ½ ton each. The total is ten tons, no matter what.

The technology variable in IPAT is more complicated. Technology refers to the efficiency of resource use *and* the efficiency of pollution control. It may also refer to the types of resources used and the types of wastes generated. Technology creates new kinds of products and materials and new kinds of waste unknown to the natural world. In this activity, several different kinds of technology factors will be used in the IPAT formula.

Thus, the IPAT formula we will use here looks something like this:

$$P \times A \times T(\text{efficiency of use}) = \text{Resource Throughput}$$

and

$$\text{Resource Throughput} \times T(\text{efficiency of pollution control}) \times \text{Emissions per unit or resource} = I\ (\text{Impact})$$

or

$$\text{Resource Throughput (Input)} = \frac{\text{Impact}}{(T \times \text{Emissions})}.$$

Now let's talk about the two IPAT examples you will be studying. You were introduced in an earlier activity to the difference between longitudinal and cross-sectional studies. In Activity 2.6, the study of England's and India's demographic transitions over time was longitudinal, while the study of 30 countries at one instant of time was cross-sectional. The IPAT formula can be applied to longitudinal *and* cross-sectional comparisons.

The first example below looks at gasoline usage in the United States between 1960 and 1995. Does technological improvement in the efficiency of motors (expressed as miles per gallon) cancel out the increase in the number of cars on the road, an increase that is the result of population growth, greater affluence of people, and other factors? Did we create more pollution from gasoline in 1960 than in 1995? The second example compares China and the U.S. and asks which country produces more coal-related emissions from power plants. Does China's large population needing energy match America's higher consumption levels? And what about the technology differential? As you fill out the worksheets, you will find out!

Part I: Longitudinal Example: Impacts of Cars in the US in 1960 and 1995

Two statistics are used here to measure affluence: A_1 = cars per person and A_2 = miles driven per car. Not everyone would agree that a longer commute to work is necessarily a sign of affluence, but annual miles driven per car relates to pleasure driving, vacationing, number and length of daily trips, and suburban sprawl -- all of which may be seen as substitute indicators of affluence.

You will calculate two environmental impacts of driving. The first, I_1, is the total pounds of CO_2 from burning gasoline. As there is no technology for gas-powered cars that can lessen the CO_2 emissions per gallon of gas, the only technology factor is the change in the miles one can drive per gallon from 1960 to 1995. Notice that to obtain the technology factor in gallons per mile, you take the inverse of the familiar miles per gallon.

A. Calculate the resource throughput (gallons of gasoline) and CO_2 impact I_1 for 1960 and 1995 in the top part of Table 4.1a (*Supporting Material 4.1a*).

In contrast to CO_2, nitrogen oxides *can* be removed from engine exhaust. The catalytic converter, required on all US cars, can reduce nitrogen oxides to an average of 38% over the lifetime of the car of what they would otherwise be in untreated exhaust. Nitrogen oxides (NO_x) contribute to two air pollution problems. In the presence of sunlight and hydrocarbons, they react with oxygen to form ozone -- the irritating component of urban smog. Nitrogen oxides also contribute to acid rain.

B. Calculate the NO_x impact I_2 for 1960 and 1995, using the bottom half of Table 4.1a (*Supporting Material 4.1a*).

C. Write a short paragraph summarizing whether the environmental impacts of driving in the US went up or down from 1960 to 1995, and suggest why this is so.

Part II: Cross-Sectional Example: Impacts of Coal Power Plants in the US and China

Next, let's do a similar analysis of the environmental impacts of coal power plants in the US and China. These two countries far exceed any other countries in terms of their total coal production and consumption. Together, they account for almost half of the 5 billion tons of coal burned worldwide each year. As you saw in the energy flow diagram of Activity 3.2, the primary use of coal in the US is electricity generation.

Again, we will develop rough estimates of two impacts. The first, I_1, is total tons of CO_2 emissions, which are more or less proportional to total tonnage, although the carbon content of coal does vary somewhat from mine to mine and region to region. Affluence is measured in kilowatt hours (kWh) per capita, which shows that US residents use 16 times more kWh per capita than residents of China. Electricity consumption per capita is highly correlated with GNP per capita, which should be obvious if you think about what the average American uses electricity for during a day.

Two resource usage technology factors are employed here. The conversion efficiency of coal to electric power, T_1, largely reflects the age and sophistication of the technology used in the power plant. China has many older power plants using outdated technology. The percentage of electricity generated from coal, T_2, partly reflects each country's resource base, but it also reflects the fact that China cannot afford to build many of the more expensive kinds of power plants -- like hydro, nuclear, or gas -- that are less polluting.

D. Calculate the resource throughput (tons of coal) and the CO_2 impact I_2 in Table 4.1b (*Supporting Material 4.1b*).

In addition to being a major source of global CO_2, coal burning also releases sulfur dioxide (SO_2) which causes acid rain. Unlike CO_2 which cannot be removed from the coal either before or after burning, there are many technologies available for removing sulfur. Coal preparation (i.e., washing) is a process that grinds, screens, floats, and spins coal to remove ash and sulfur from the coal *before* it is burned. Although its effectiveness varies widely from one type of coal to the next, it generally can remove roughly one-quarter of the sulfur from the coal. About half of all U.S. coal is washed prior to shipping.[20] In China, however, environmental laws are not as strict, and most buyers are unwilling to pay extra for washed coal. Only about 8% of steam coal is washed before being shipped to power plants in China.[21]

Sulfur can also be removed during the post-combustion stage, i.e., from coal smoke. This technology is known as flue gas desulfurization (FGD), or "scrubbers" for short. Scrubbers are very effective, but also very expensive. They remove about 90% of the sulfur dioxide from coal smoke, but they add 50% to the total investment cost of a power plant. For this reason, scrubbers are virtually nonexistent in investment-starved China, but they have been installed on approximately 25% of U.S. coal-fired power plants.[22]

Rough estimates of the sulfur removal efficiencies by these two pollution control technologies have been input as T_3 and T_4 in the bottom half of Table 4.1b for coal (see the footnotes below). These factors represent the percentage of sulfur in the coal that gets emitted as pollution -- the higher the numbers, the worse the pollution.

E. Complete table 4.1b (*Supporting Material 4.1b*) to estimate whether China or the US creates more sulfur dioxide pollution.

F. Write a short paragraph summarizing which country causes more environmental impact from their coal-burning power plants, and why you think this is so.

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[20] The percent of sulfur removed by coal washing in the US is therefore 12.5% (0.5 × 0.25 = 0.125), and the percent untreated is therefore 87.5% (1-0.125 = 0.875).

[21] The percent of sulfur untreated by coal washing in China is therefore roughly 98% [1-(0.08 × 0.25)= 98]

[22] The technology factors for scrubbers are thus estimated as follows. Assuming 25% of US power plants remove 90% of their sulfur emissions, the share removed is 22.5%, and the share untreated is 77.5% (1 - 0.225 = 0.775). Thus, roughly 77.5% of sulfur burned by US power plants is emitted as pollution to the atmosphere. For China, with no scrubbers, the proportion emitted as pollution is 100%.

Student Worksheet 4.2

Activity 4.2 Same World, Different World Views

The *Background Information* from Unit 1 introduced you to the main debates in the scientific literature about population and the environment. Now that you have had a chance to learn more about the dynamics of population growth and energy use, you are better equipped to make sense of these debates. Remember what we said before about *schools of thought,* that is, ways of looking at the world. What is the nature of their disagreements: do they part company on *facts* or *values? Where are they coming from?*

In this activity, you will be assigned to argue for a particular viewpoint represented in the population-environment debate. Your instructor will assign several articles for everyone to read. It is important to read them all, not just the one(s) for the point of view you are assigned. Knowing the opposition's viewpoint is a key to debating or negotiating with its representatives successfully.

After you have read the assigned readings, two (or three) students in your country group should choose to be a representative of one of the viewpoints offered. (You don't have to agree with the point of view to represent it in the debate -- you may want to use this opportunity to explore what lies behind a different mind set!) Then, meet with those students who have chosen to represent the same viewpoint as you have and agree on the main arguments. Get the arguments from your chosen point of view really clear and take notes on them on an extra sheet of paper because you will have to argue them in front of those having a different opinion!

One or more of you should then make a short presentation of your arguments in front of the class. After all viewpoints have been presented, debate with each other! Argue for your position, but remember, the others might not be wrong, and you should respect their views. The point is to use the facts that you know and to address people's beliefs and values to convince them of your viewpoint.

After the debate, reflect for a moment on what you have learned. As you summarize the main points and arguments, take some notes. You will need them later.

Student Worksheet 4.3

Activity 4.3 Regional Case Studies

This activity is a team assignment for your country group. The task is to present clearly and convincingly the environment/population/economy situation of your region/six countries to the rest of the class. For this presentation, you will need some quantitative data, your notes on the arguments you heard in the previous activity, and all your notes and knowledge that you have from earlier sections of this module (i.e., basic understanding of population characteristics and dynamics, knowledge of how to measure economic development and energy usage, etc.).

Before you can actually get up in front of the class and give your presentation, you need to meet with your fellow country group members and discuss a step-by-step work plan of how to prepare the class presentation. Here are some things you need to think of:

- What is/are the most adequate variable(s) (indicators) for each category mentioned on the worksheet (provided by your instructor)?
- Where will you get the necessary information, and who will acquire it for which country? You need quantitative data, possibly for two or more points in time (include stories only if you are familiar with your country of choice and/or if you have enough time to read more).
- You need to compile the worksheet and then figure out where the countries fit in the model of demographic transition, how the countries are changing (in all categories), how fast they are changing, and why they are changing.
- Check your first answers against the arguments presented in the readings and in your notes from the discussion in Activity 4.2.
- How are you going to do the presentation? Do you need overhead transparencies? Do you need to present data in tables? Or use some graphics? What are your main arguments? Who is going to be involved in actually giving the presentation?

Make sure everyone gets involved. Remember, it's a team effort. It might be best if everyone feels responsible for at least one country (of course, that depends on how many people are in your group). You only get 10 or a maximum of 15 minutes for your presentation, so you might want to do a practice run before class to make sure you make a good case. At the end of your presentation, you should be able to say which of the three viewpoints you discussed in the previous activity best describes the situation in your region -- and why.

Student Worksheet 4.4

Activity 4.4 Final Paper: Synthesis and Geographic Differentiation

This activity is a paper in which you can put the pieces of this module together. Write a 5 to 10 page essay (double spaced, 1-inch margins, 12 pt. font) in which you discuss the relationship between population, affluence (energy use and economic well-being), technology, and the throughput of energy-related emissions and pollution to the environment.

In this essay you should not take up just one of the readings, and argue for or against it, but cite the readings that spoke most to you throughout this module (i.e., those stating arguments right up your alley or squarely opposed to it!). You may also use your notes from previous class sessions, especially those that remind you of regional differences in this relationship. Use examples to make your points. Be creative! This is YOUR chance to argue your case!

4 Only One Earth: From Controversy to Constructive Understanding

Answers to Activities

Activity 4.1 IPAT in Action

Answers to this activity are as follows:

A. 1960 40.4 billion gallons per year, 768 billion lbs of CO_2.
1995 93.4 billion gallons per year, 178 billion lbs of CO_2.

B. 1960 4.84 billion lbs of NO_x.
1995 4.26 billion lbs of NO_x.

C. Gasoline consumption and carbon dioxide emissions rose from 1960 to 1995, despite the 38% improvement in miles per gallon technology. The main factor canceling out the technology gain is affluence: the number of cars per person increased 73%, and the miles per car increased by 25%, for a total 117% increase due to affluence. Population also increased by nearly 50%. Thus more and richer Americans used more gas despite the mileage improvements. It is worth noting that *all* of the miles per gallon gains were achieved during the 1975-1991 time period. Miles per gallon actually declined from 1960-75 and 1991-95. The latter decline can be attributed to the increasing popularity of minivans and off-road, sport utility vehicles.

In contrast with CO_2, NO_x emission fell from 1960 to 1995. This is because catalytic converters can remove about 62% of all NO_x emissions from auto exhaust. In some ways, then, our air is getting cleaner over time, but in other ways it is getting dirtier. It is especially true that older cars are responsible for a highly disproportionate share of nitrogen and sulfur oxide pollution. However, none of these technologies affect carbon dioxide. Solar, natural gas, or hydrogen powered cars would lower CO_2 emissions, but electric cars would not necessarily do the trick if the electricity were generated by coal-fired power plants.

D. US: 828 million tons of coal, 1738 million tons of CO_2
China: 472 million tons of coal, 991 million tons of CO_2

E. US: 12.6 million tons of SO_2
China: 10.4 million tons of SO_2

F. Coal-fired power generation in the US still consumes far more coal than power generation in China and produces proportionally more carbon dioxide as well. The huge 16:1 difference in electricity consumption per person (affluence) is responsible for the US's greater global environmental impact. Despite a population 5 times larger, less efficient power plant technology, and a heavier reliance on coal, China still is 43% behind the US China is also behind the US in sulfur dioxide emissions, but the gap between the two countries is smaller because of the sulfur control technologies in use in the US.

China is catching up rapidly, however. Their GNP has been growing at an average rate of over 10% per year for nearly 15 years. Electricity consumption has been growing even faster than GNP, as the Chinese electrify more villages, develop their service sector, adopt more modern technology, and move into the consumer age. In fact, electricity production is considered to be at least 20% below demand in China, creating a situation of constant shortfall and frequent brownouts and blackouts. Electricity consumption will continue rising faster in China, in that the percentage of Total Final Consumption of energy coming from electricity is only about 8%, compared with 15-20% typical of the developed countries. China's plans for building more power plants dwarf those of any other country. With the affluence gap narrowing, China will surely surge past the US in a few years' time. (Instructors should be sure to mention that the entire Third World is not making economic progress anywhere nearly as fast as China.)

It must also be noted that China actually consumes far more coal than the US in total. Overall, China consumed 1.38 billion tons in 1994, compared with 930 million tons for the US. The difference is accounted for by the fact that China uses coal for all kinds of end uses -- transport, residential, commercial, military, construction, and industry -- whereas in the US coal is mainly used for power generation and steel making.

Activity 4.2 Same World, Different World Views

There are no specific answers that the instructor should look for in students' debates. Each debate will vary depending upon the countries chosen and the students involved. In general, you may assess students using the following guidelines:

- Did they demonstrate a good understanding of the texts?
- Were they actively involved in the class debate?
- Did they present convincing arguments?
- Did they demonstrate civility and respect for their classmates' arguments?

Activity 4.3 Regional Case Studies

Students' presentations will vary depending upon the country groups used and the time allowed for preparation and presentation. You may use the following guidelines to assess the students' work:

- Was the presentation factually correct, and did the students provide good citations of data sources?
- Did the students demonstrate a good understanding of the region/country's situation?
- Did the presentation demonstrate the involvement of members of a team in an equitable way?
- Was the presentation clear and concise, and did it make good use of graphics and visuals?
- Did the students make reasonable suggestions for "remedies" (policies)?

Activity 4.4 Final Paper: Synthesis and Geographic Differentiation

In assessing the final papers, you may want to consider the following:

- Did it synthesize concepts, ideas, etc.?
- Did it compare across regions?
- Did it contain good citations?
- Did it demonstrate a clear organization of thoughts?

Glossary

Note: Terms that appear in bold in the right column appear elsewhere in the glossary.

agricultural involution	a term coined by C. Geertz in 1963 to describe the over-reliance on labor-intensive methods in agricultural production that is typical in situations of population pressure on scarce land resources. Agricultural production is intensified in terms of output per hectare (not output per capita!) by increasing the labor force, not by introducing any new technologies or changing social and economic structures.
anthropocentric	viewing and interpreting the world exclusively through the lens of human values and human experiences.
anthropozoic era	a period (according to Italian geologist Stoppani [1873] in which the power and universality of humanity's influence on the natural world is of comparable magnitude to the great geologic, energetic, and biotic forces of the earth.
birth rate (crude)	number of births in a single year per 1,000 population.
Boserupian perspective	originated from work of agricultural economist Ester Boserup. This approach to viewing the relationship between population and the environment suggests that technological, economic and social innovations induced by "population pressure" lead to the intensification of agriculture. Population growth requires and produces an increase in food supplies.
capital	the sum of all resources used (natural resources, money, technologies, knowledge, etc.) as investment in the production of goods and services.
carrying capacity	the number of people or organisms that can be sustained by a given set of land resources and a given level of technology.
CFCs	chlorofluorocarbons; a compound used in refrigerants, air conditioners, aerosol sprays, etc. that is released into the atmosphere and contributes to the destruction of **stratospheric ozone**.
causal linkages	explanatory mechanisms that order relationships between variables in a cause and effect sequence; causal linkages are important because the way in which we view causes drives the process of finding and evaluating possible solutions.

Cornucopian perspective	very optimistic school of thought in the population-environment debate that sees the earth and its resources as plentiful and virtually unlimited, and that finds no negative impacts of population; commonly associated with Herman Kahn and Julian Simon.
CO_2	carbon dioxide; a gas emitted in the process of burning fossil fuel such as coal or petroleum. CO_2 emissions have grown exponentially over the past 40 years and are accumulating in the earth's atmosphere. This accumulation is tied to the enhanced **greenhouse effect** and probably to the observed warming trend of the past century.
crude population density	population per square mile (or square kilometer) of land.
cultural/political ecology	an approach to the study of human-environment relations; cultural ecology proposes that similar configurations of environment and technology tend to be functionally and causally related to similar social organizations. Cultural ecologists study how humans and cultures adjust through subsistence patterns to the unique character of their local environment. Political ecology has a slightly different emphasis in that it stresses political economy and conflicts more than cultural institutions and patterns.
cycles	a set of **flows** and **stocks** that enables a system to function indefinitely.
death rate (crude)	number of deaths in a single year per 1,000 population.
delay	a time lag between a cause and an effect.
demographic transition theory	a theory based on the historical experience of Western industrial countries which describes the process of change from high **birth rates** and **death rates** to low birth and death rates as related to changes in economic development.
desertification	process whereby an area of land becomes desert-like, typically involving impoverishment of an ecosystem either through climatic or human impacts or a combination of the two so that the land develops desert-like characteristics (e.g., bare soil, diminished plant cover, severe erosion, and other physical symptoms of soil degradation).
direct linear relationship (linearity)	a relationship between two variables (a cause and an effect) whereby a given amount of change in one variable is associated with a given amount of change in the other.
doubling time	the number of years it takes for a population to double in size.

environmental externalities	the real costs to society of environmental degradation which, however, do not have to be paid directly by the economic agent that caused them; known as externalities because they are costs that are external to the firm or individual who caused them (see also **social costs**).
exponential growth	occurs when a variable (like population) is multiplied by a fixed number in each time period; for example, a bank account continually earns interest by multiplying the amount in the account by the interest rate. The account grows exponentially because it earns interest not just on the original amount, but also on the interest added in the previous period of time.
equilibrium	a state in which the dynamic forces in a **system** are in balance, or in equilibrium state, i.e., where inflows equal outflows.
feedback loop	reciprocal effect in a system whereby a change in one variable influences changes in other variables which in turn influence the initiating variable by either reinforcing the tendency of the **system** to change (**positive feedback**) or dampening it (**negative feedback**).
fertility rate (general)	the number of children ever born per 1,000 women aged 15-49 in a given year.
flows	changes of stocks or the movement of energy, materials, and information in a **system**.
GDP	gross domestic product; a monetary measure of the value (at market prices) of goods and services for final use produced within a national economy over a given time period, usually a year or a quarter.
GNP	gross national product; a monetary measure of the value (at market prices) of the goods and services produced within a national economy (or the **GDP**), plus net income from abroad, over a given time period, usually a year or a quarter.
global warming	the increase in average global temperatures; the term is used today to refer to temperature increases that are thought to be caused by human activities enhancing the atmospheric **greenhouse effect**.
greenhouse effect	refers to the role of various trace components of the atmosphere (such as $H_2$0, **CO_2**, etc.) in reabsorbing certain wavelengths of the energy spectrum radiated from the earth's surface and thereby increasing the global temperature. This effect occurs naturally but is augmented by human activities such as burning of fossil fuels and land cover changes since these emit trace gases that become further concentrated in the atmosphere (enhanced greenhouse effect). Humans have also added a new class of greenhouse gases which do not occur naturally (e.g., **CFCs**).

Green Revolution	a term that historically refers to land reform in Eastern Europe in the 1920's and 1930's, but since the 1960's has become generally known as the adoption of a package of agricultural practices (especially those supporting high-yield grains) in developing countries, especially Asia.
hidden momentum	refers to the phenomenon that even if the **fertility rate** drops to the replacement level (2 children per couple) overnight, the population will continue to grow at least another 50% before it stabilizes. This occurs because population growth approaches zero only when the birth/death ratio approaches one and the population is not disproportionately made up of those of, or entering, child-bearing age.
human agency	influence of human actors in affecting changes, e.g., determining the outcomes of social processes or bringing about certain types of environmental change.
human factors	the human driving forces behind global change; human factors tend to be difficult to quantify or model. They range from technology to consumption, affluence, history, social organization, institutions, political economy, attitudes, and beliefs (values).
individual vs. collective behavior	one views individual behavior as the cause of environmental degradation or resource depletion (e.g., individual decisions on the desired number of children, economic consumer behavior, contraceptive choices); the other views collective behavior as the driving force of such changes (e.g., sociocultural conditions such as class conflicts or poverty).
limits to growth	a phrase that gained currency as the title of a report issued in 1972 by the Club of Rome on global resource and pollution trends. The classic work on limits dates back to **Malthus**' *Essay on the principle of population* (1798) which depicted food supply as a fundamental check to demographic and economic growth. This argument has been extended to other natural resources and to the earth's capacity to absorb pollution.
Malthusian perspective	originated in the late 18th century from the writings of Thomas Malthus, who postulated that the relationship between population and resources is governed by constraints. Population tends to grow faster than the means of subsistence, which can lead to the collapse of populations and their resource supply.
mediating approach	a variation of the **multiplicative perspective** on the population-environment relationship which tends to put greater emphasis on the human dimensions and the interactions of social organizations, culture, institutions, and the political economy with nature. The mediating approach is often found in **vulnerability** research.

multiplicative perspective	population variables such as growth, size, density, and distribution interact synergistically or in a multiplicative fashion with other factors such as consumption and technology. While population, consumption, and technology may be seen as independent causes of environmental impacts, this perspective holds that crucial emphasis should be placed on the combined effect of these factors.
negative feedback loop	loop within a system that naturally offset or dampen the tendency of the **system** to change.
neo-classical economics	theory of the allocation of scarce resources through the market, regulated by the interaction of supply and demand, which serves to allocate resources and to distribute income through the determination of prices for goods and factors of production.
non-equilibrium models	models in which the relationship between variables shows no obvious order or periodicity in either frequency or amplitude and which exists in a state away from **equilibrium**; this makes forecasting and prediction of future states extremely difficult, if not impossible.
non-renewable energy sources	energy sources that are used up and eliminated and which cannot be regenerated -- at least not on a human time scale (example: oil).
non-linearity	in the relationship between cause and effect, non-linearity refers to the condition where equal amounts of causes do not always produce equal amounts of effects.
ozone hole	the colloquial term for the thinning of the stratospheric ozone layer. The ozone layer is that portion of the upper atmosphere in which ozone (O_3) is highly concentrated. The ozone layer absorbs large amounts of dangerous ultraviolet radiation, thus protecting life on the earth's surface from radiation damage (such as skin cancers, eye diseases, reduced photosynthetic activity, etc.).
paradigm	the working assumptions, procedures, and findings routinely accepted and employed by a group of people; a paradigm defines one's view of the world and the approach one takes to defining problems, researching them, and solving them.
physiological population density	population per square mile of agricultural land.
(crude) population density	a measure of the number of persons occupying an area, expressed as persons per unit of area, such as 1,000 persons per square kilometer.

positive feedback loops	loops within a **system** that perpetuate initial changes and thereby cause these changes to snowball or be accentuated; in the human world, positive loops that reinforce bad changes are called "vicious circles."
productivity	a measure of output relative to input, most commonly used in economics, but also used in ecology.
random sample	a **sample** chosen in such a way that each object or unit has an equal chance of being selected.
renewable energy sources	those energy sources that can be consumed and be restored after use such that they are again available for future use; examples include solar, wind, or water energy, but also biological energy sources such as wood since forests can regrow
sample	in statistics, a subset of the entire set (population) of units or objects of study
sampling frame	a list of all units from which a **sample** is selected.
social costs	these are real costs to society of environmental degradation which, however, do not have to be paid directly by the economic agent that caused them; also known as **environmental externalities** because they are costs that are external to the firm or individual who caused them.
stagflation	a period of economic stagnation (no growth) plus inflation; such a period occurred in the late 1970's.
stocks	accumulated amounts of energy, materials, or information that along with **flows**, comprise a **system**
stratified sample	a **sample** taken from a set of units or objects that have been divided into groups based on a chosen similarity (i.e., grouping the set of all countries into continents and then sampling from each continent); this statistical technique helps ensure that all groups are represented in the sample
stratospheric ozone	a chemical compound (O_3) that occurs concentratedly in the stratosphere or higher atmosphere (see **ozone hole** and **CFCs**)
system	any interconnected set of elements that can be seen as serving a purpose; changes in one part of the system affect other parts; systems are more than the sum of their parts and behave in ways that may not be obvious when one studies the parts individually.
tragedy of the commons	the idea that in the absence of public control of a commonly owned (public) renewable resource, it will be to the private advantage of all individual users to maximize their separate shares, even though the combined effect of their

	individual use is to diminish the total yield or destroy the resource altogether (examples: marine water pollution, emission of greenhouse gases).
urban heat island effect	the commonly observed condition of increased ambient temperatures in cities compared to those in nearby, non-urban areas. The urban heat island effect is caused by the increased absorption of long-wave radiation (heat) by materials such as concrete, pavement, stone, etc.; the slow release of this heat can increase the ambient air temperatures by several degrees.
vulnerability	a condition of systems or individuals that makes them susceptible to the impacts of a hazardous event. Vulnerability research is rooted in the hazards school within geography that places emphasis on who is most vulnerable to disasters, hazards, or the negative effects of global change.

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Supporting Materials

The materials in this section support the background information and the student activities. Each *Supporting Material* is numbered according to the section or activity in which it may be used. For example, *Supporting Material 1.1* accompanies *Activity 1.1*. Materials that are intended to support the *Background Information* in the module, such as overhead originals or other documents, are numbered according to the Unit. For example, *Supporting Material 3* accompanies the *Background Information* for Unit 3.

Overheads for In-Class Presentations and Discussions

The following pages contain overhead originals that cover in brief form the material contained in the *Background Information* of Unit 1. The instructor may use these in the class to summarize or repeat the information students read in this section of the module or to organize lecture material.

Note, the matrix is for your students to fill in with examples during the class session.

Human Driving Forces of Global Change: Introduction

- Four distinct, but interacting *mechanisms* by which humans have impacts on the natural world (Clark 1988):

Resource use :	the removal of materials and energy from natural subsystems or the redistribution or sequestering of them within those subsystems
Pollution:	release of all kinds of pollutants into different natural subsystems
Surface change:	transformation of the physical surface of the Earth, its characteristics, and its habitats
Species removal:	removal or manipulation of species through various means, including harvesting, hunting, genetic alteration, etc.

Types of Impacts	**Main Types of Human Activities**		
	Agriculture	***Industry***	***Energy Consumption***
Resource Use			
Pollution			
Surface Change			
Species Removal			

(Source: constructed after Clark 1988)

History of the Global Emphasis in Environmental Studies

- Prior to 1970s: environmental problems were seen as local events, not linked globally.

- Research in the 1970s began to connect environmental problems globally; widespread publicity for the "limits to growth" concept: exponential population growth will exceed the carrying capacity of the Earth.

- Late 1970s "Limits to growth" thinking under attack for historical, scientific, cultural, and economic reasons; environmentalism suffered a loss of its unity and appeal as a result.

- Mid-1980s: "global change" emerged as a new unifying banner for the environmental movement and the environmental sciences. Defining issues: the "ozone hole," the destruction of tropical rainforests, and the greenhouse effect. Defining solutions: technology, market mechanisms, and partnerships with private industry.

- Current debates in these areas indicate differences in world views and scientific approaches that echo past environmental debates:

How Important is Population in Environmental Change? -- Different Perspectives:

1. The relationship between population and the environment is *direct and linear*
   1a. *Malthusian*: there is a maximum number of people that a given set of resources can sustain (carrying capacity); exceeding it will lead to ecological and social collapse
   1b. *Boserupian*: while resources are limited and population may grow faster than its food supply, population pressure can lead to technological, economic, and social innovations which in turn lead to intensification of agriculture
   1c. *Cornucopian*: population does not have any negative impact on the environment; the Earth is plentiful; environmental degradation must be explained through other variables; the free market will solve all resource scarcities

2. The relationship between population and the environment is multiplicative/synergistic. Population variables such as growth, size, density, etc. interact synergistically with other factors such as consumption and technology (Example: I = P*A*T, quantitative system dynamics models)

3. Mediating approach: a variation of the multiplicative/systems perspective that puts greater emphasis on the human dimensions and interactions of social organizations, culture, institutions, and the political economy with nature. (Example: cultural/political ecology; vulnerability research in geography)

Key Population Concepts

1. *Exponential growth* occurs when things grow as a percentage of their base amount, like a bank account, which continually earns interest not just on the principle, but on the previous interest earned.

2. *Doubling time* is the number of years it takes for a population to double in size.

3. *Demographic transition theory* is based on the historical experience of western industrial countries and describes the process of change from an equilibrium of high birth rates and death rates to a different equilibrium of low birth and death rates as related mainly to changes in economic development.

4. The *hidden momentum* of population refers to the phenomenon that even if the fertility rate drops to the replacement level (2 children per couple) overnight, the population will continue to grow substantially before it stabilizes. This occurs because population growth will stop only when the number of births and deaths are the same -- not necessarily when the number of births and the number of parents are equal.

Energy Use: Consumption Trends

- There is a strong positive correlation between energy consumption and gross domestic product (GDP, the monetary value of goods and services produced by a national economy) per capita: higher GDP/capita means higher energy consumption/capita.

- This relationship is used as an explanation: in order for a worker to produce more per hour, he or she needs to be equipped with better goods, equipment, etc. Or: to increase productivity one needs to increase investment. Often this means increasing energy input.

- If people everywhere, in all social classes, want to become richer, and if we are concerned about the environmental impacts of economic growth, then we need to ask whether economic growth and energy consumption are unchangeably tightly linked, or whether there is room for loosening or even breaking this linear relationship.

- - Why do Japan and Switzerland have higher GDPs per capita than the US, but only roughly half of the energy consumption per capita?
  - Can an economy grow without its energy consumption growing?
  - If so, how? Is becoming more energy efficient enough?
  - If not, does that mean lower economic growth rates? Lower standards of living?
  - How much energy is left for the future? How much can we consume?

Systems Terminology

Systems concepts are useful in understanding how the trends in population, energy, and pollution fit together.

- A *system* is any interconnected set of elements that can be seen as serving some purpose. Systems are more than the sum of their parts, i.e. they behave in ways that may not be obvious when one studies their parts individually. In a system, a change in one element affects other elements.

- Systems are composed of stocks and flows. *Stocks* are accumulated amounts of energy, materials, or information. *Flows* are the rates of changes of stocks or the movement of energy, materials, and information. For a system to function indefinitely, stocks and flows must be interconnected in a *cycle*.

- When inflows equal outflows the system is in balance or in a state of *equilibrium*.

- *Feedback loops* are chains of cause and effect that either accentuate (*positive feedback*) or dampen (*negative feedback*) the initial direction of change.

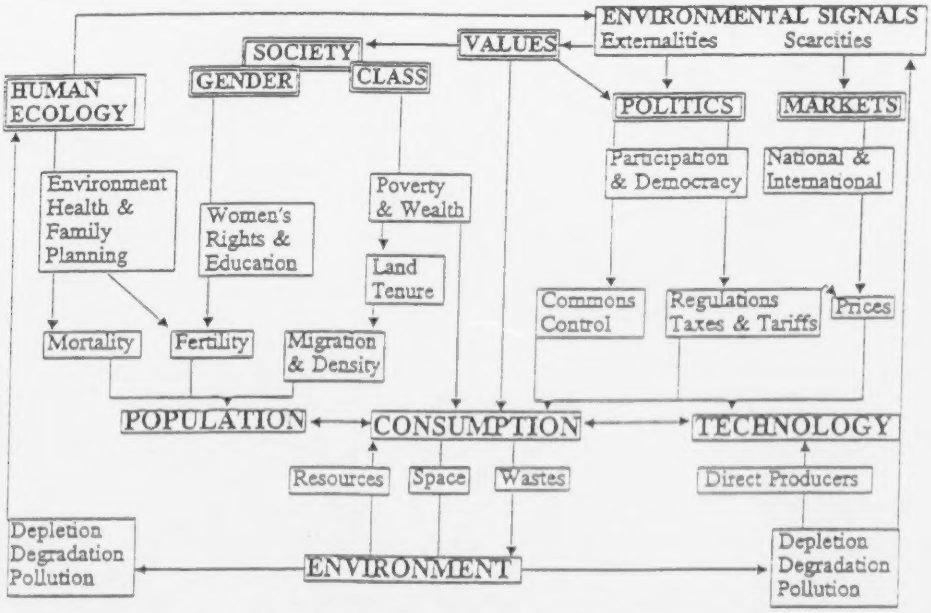
- A *delay* refers to *lag time* between cause and effect in a system.

- A relationship between cause and effect whereby equal amounts of cause always produce equal amounts of effect is a *direct linear relationship*. *Non-linearity* refers to the condition where equal amounts of cause do not always produce equal amounts of effect.

The Quantitative Systems Dynamics Approach

The quantitative systems dynamics approach falls squarely in the multiplicative/synergistic category discussed in Unit 1. Systems dynamics was started as a way of looking at factory dynamics (Forrester 1961), but was quickly extended to studying a whole variety of systems, such as ecosystems, climate systems, hydrologic and nutrient cycles, traffic systems, computer systems, and economic systems, to name a few. The figure below illustrates a systems view of the human-environment nexus.

A (Simplified) Systems View of the Human-Environment Nexus


ENVIRONMENTAL SIGNALS
Externalities
Scarcities
SOCIETY
VALUES
GENDER
CLASS
HUMAN ECOLOGY
POLITICS
MARKETS
Participation & Democracy
National & International
Environment Health & Family Planning
Women's Rights & Education
Poverty & Wealth
Land Tenure
Commons Control
Regulations Taxes & Tariffs
Prices
Mortality
Fertility
Migration & Density
POPULATION
CONSUMPTION
TECHNOLOGY
Resources
Space
Wastes
Direct Producers
Depletion Degradation Pollution
ENVIRONMENT
Depletion Degradation Pollution

Source: Harrison. 1994. *Human Ecology Review*, 1(2): 268, his Chart 1. Reprinted with permission.

The popular use of the word "system" is not far off from its scientific meaning. A **system** is any interconnected set of elements that can be seen as serving some purpose. The key word is "interconnected." In a system, accumulated amounts of energy, living things, materials, or information **flow** from one **stock** to another. These flows can be interconnected to form **cycles**. A change in **inputs** or **outputs** affects one thing, which affects others, and in many cases eventually comes back to dampen or accelerate the thing that initially changed in what are called **feedback loops**. Those loops that naturally offset the initial change are called **negative feedback loops**, not because they are bad, but because they reverse or minimize the changes. In fact, negative feedback loops are usually good in the sense of returning things to "normal" (that is, to a beginning state, or an **equilibrium**). Those loops that come back and cause the initial change to snowball or accelerate are called **positive feedback loops**. In human affairs we have a special name for feedback loops that reinforce bad changes: we call them "vicious circles."

Systems modeling plays a central role in the current global warming debates, just as it did in the past debates about *Limits to Growth*. In both cases, synergistic/multiplicative/systems models have been used to predict what may happen to the system as the absolute scale of the world's population and its industrial and agricultural output grows to a scale never before known in human history. Known physical, biological, demographic, and economic relationships "play themselves out" in a computerized experiment. What sets this kind of work apart from non-systems, non-synergistic approaches is the attempt to integrate all the relevant relationships and subsystems in the analysis.

A key characteristic of systems is that they behave in ways that may not be obvious when one studies their separate parts. There is a popular saying that the whole (the system) is more than the sum of its parts. An idea that is crucial to the global systems paradigm is, however, that the whole system may be *substantially less* than the sum of its parts. It is less in the sense that individual environmental and social systems might be able to cope with one environmental threat successfully, or even several, but not with threats coming from all sides. In the global warming systems scenario, the ability to cope with CO_2 is lessened by more methane from cows, less rainforest to absorb carbon, less grazing lands due to desertification, etc. Likewise, in the *Limits to Growth* systems scenario, humankind could probably solve any one given pollution problem through technological change, were it not that capital is also needed to irrigate and fertilize more farmland, to educate, house and heal more people, to control more pollution, and to churn out consumer goods and build the machines that will produce all these other forms of capital. In contrast, many of the optimists who have opposed the mostly pessimistic conclusions from global systems models rely mainly on statistical evaluation of data of one or a few relationships at a time. The two groups emphasize two different kinds of scientific cautiousness. The systems modelers seem to see their roles more as early-warning sirens to alert the world to a very real and dangerous possibility, while the statistical modelers seem not to want to pronounce something as scientific fact until the evidence is definitive.

In one sense, the systems approach is the pinnacle of multiplicative/synergistic thinking in that both the multiplicative aspect and the synergistic relationships are explicitly quantified and integrated.[23] Others, however, feel that such complex interrelationships are incapable of being accurately quantified with the current state of knowledge. As such, it often draws fire from those who agree with both its values and facts but disagree with its computational method (see Figure 4 in Unit 1). In adopting our own perspectives, we must keep in mind that global systems models are simply attempts to approximate and organize our understanding of these complex phenomena. Even if we think such models will never be capable of predicting the future reliably, we need not throw out the systems-thinking "baby" with the global-modeling "bathwater."

---

[23] For instance, IPAT is quantifiable, but its simplicity prevents it from being used to predict actual behavior over time. Similarly, many explanations of synergistic population-environment relationships remain on the level of conceptual flow charts.

Is CO_2 Emission a Form of Pollution?

Researchers have found that, for the general public, CO_2 emissions and the so-called greenhouse effect are often conflated with the more familiar notions of pollutants and pollution, respectively (see e.g., Bostrom et al. 1994, Read et al. 1994). This is understandable in light of the fact that we have come to view the greenhouse effect and CO_2, one of the main contributing radiatively active gases, as something undesirable, as something similarly "bad" like pollution. The conflation also makes sense given that everything we term pollution only becomes such once it is "emitted" into the environment, just like CO_2 needs to be emitted to contribute to the greenhouse effect. Finally, pollution and CO_2 emission can be characterized to some extent by similar descriptive categories, such as sources and sinks, the scale and scope of impacts, etc. (see below).

There are, however, areas in which this conflation is problematic. First, CO_2 is a natural compound without which life on Earth would be very much restricted if not impossible. CO_2 is essential to the *natural* greenhouse effect, which creates a temperature regime in which life has been able to evolve. Also, CO_2 is (along with water) *the* essential "food" for plants, or more appropriately, for our primary producers on which the food web of all higher life forms depends. This does not hold true for pollutants. While it is correct that certain compounds become nuisances only in toxic concentrations, we often do not know where those thresholds lie.

The second reason why equating CO_2 emission with pollution is misleading, lies in its behavioral implications. The main causes for the anthropogenically enhanced greenhouse effect are increasing emission of radiatively active gases, like CO_2, methane, nitrous oxides, and CFCs via fossil fuel combustion, certain agricultural practices, and the destruction of vegetation and carbon sinks, and changes in albedo (e.g., through deforestation). It was found that even educated lay persons do not fully understand these general causal linkages. When asked what they personally could do about climate change, they frequently referred to *good environmental practice* as the "solution" (Read et al 1994). As these authors explained it, "things which seem bad for the environment [as e.g. pollutants] also cause global warming, while environmentally friendly actions [like avoiding the use of spray cans, driving less] reduce global warming" (Read et al. 1994: 980-981, remarks in brackets added). This typical answer only touches on the major causes of global climate change and clearly reflects inadequate information about this complex phenomenon.

In trying to understand complicated new phenomena, we use existing mental constructs or models to help us "make sense" and to decide on appropriate behavioral changes. The mental model "pollution of the environment" is not sufficient to accommodate the complexity of "global climate change." It is therefore advisable not to use "pollution" and "CO_2 emissions" interchangeably. A class discussion of the differences and overlap of the terms could help to dismiss misconceptions of "what we personally can do about climate change." This discussion should also clarify that there are more "energy-use related emissions" than just CO_2 (e.g., sulfur dioxides, nitrous oxides, ash, water vapor, heavy metals, and other inorganic and organic petrochemical compounds), the latter of which are not discussed in this module.

The Definition and Dimensions of "Pollution"

Fellman, Getis, and Getis (1995: 510) define pollution as "the.introduction into the biosphere of materials that because of their quantity, chemical nature, or temperature have a negative impact on the ecosystem or that cannot be readily disposed of by natural recycling processes." This definition contains a number of useful points. First, some substances like dioxins, solvents, and PCBs fit the popular definition of pollution as being highly toxic substances. They cause cancers even in minute quantities because their chemical forms were intentionally designed to withstand biological or chemical breakdown. Second, there are characteristics (like temperature) that can render a material -- even if it is pristine water -- harmful to life. Third, and most relevant to this module's focus on human driving forces, is the amount of the material flow. For instance, a small amount of human or animal waste spread over a field is fertilizer, but hundreds of tons of raw sewage dumped into a harbor is pollution because it is more than the natural decomposing processes can handle, with the result that sewage and disease-causing fecal bacteria build up.

In "reasonable" quantities, CO_2 is not a pollutant -- all mammals breathe in oxygen and breathe out CO_2. However, as Figure 2 above (see Unit 1 of module) showed, the amount of CO_2 being produced by the human economy has grown enormously in the 20th Century. If the natural recycling processes, like forests, plankton, and other things that absorb CO_2 out of the atmosphere cannot remove it as quickly as it is emitted, the concentrations will build up. If the higher CO_2 levels in the atmosphere then trap a significant amount of re-radiated thermal radiation that would otherwise have escaped from the earth's atmosphere -- the basic global warming scenario -- then CO_2 will indeed have had a negative impact on ecosystems by way of hotter temperatures, altered rainfall patterns, and melting of polar ice caps. In this respect large quantities of CO_2 have effects that resemble those of other pollution.

This module focuses on the forces that drive the total global volume of energy-related CO_2 emissions created by the human economy. It is instructive, however, to discuss the enormous variability of pollution. As summarized in the table on the next page, pollution is actually a multidimensional phenomenon for which total global volume is not necessarily the key factor (Haggett 1983). First, the sources of pollution vary geographically, including stationary points (factories), mobile points (cars), or areas (farms). Sources also vary on the temporal dimension. Some, such as smokestacks, emit pollution almost continuously; others, like automobiles, which are used occasionally but pollute most after a cold start, are recurrent but noncontinuous; still others, such as nuclear releases or oil tanker spills, are random episodic events.

Second, there can be a great deal of variability in the pathways of pollutants, i.e., in the media they move through, the time lapsing between release and impact, and in the manner in which a pollutant is kept in the environment. Concerning the geoecological pathways, materials most commonly move through the atmosphere (air), the hydrosphere (still or standing water), the pedosphere (soils) and/or the biosphere (organisms). Temporally, the effects can be immediate (e.g., the Bhopal toxic release killed hundreds within a day) or delayed (e.g., CFC molecules released fifteen years ago are just now working their way into the ozone layer). And finally, pollution can be magnified or recirculated biologically or chemically. For instance, the average free chlorine atom from a single CFC molecule will break down 100,000 ozone molecules before it itself is rendered harmless by UV radiation or by reacting with methane (another pollutant) to form hydrochloric acid and falling to earth as acid rain (yet another pollutant). In biotic systems, a process known as bioaccumulation occurs whereby toxic waste is found in higher concentrations in the flesh and organs of creatures at higher levels of the food chain, as shrimp eat plankton, fish eat shrimp, and herons eat fish. Humans, of course, along with other carnivores are at the apex of the food chain.

Dimensions of Pollution Variability

1. ***Source of Pollutants***
    - *A. Geographical*
        - - point/area
        - - mobile/stationary
    - *B. Temporal*
        - - continuous/recurrent/episodic
2. ***Pathways of Pollution***
    - *A. Geoecological*
        - *- water, air, soil, organisms*
    - *B. Temporal*
        - - immediate/delayed
    - *C. Recirculation*
        - - none/recirculating/bioaccumulating
3. ***Sinks of Pollution***
    - - atmosphere/hydrosphere/lithosphere
4. ***Impacts of Pollution***
    - *A. Geographical*
        - - local/regional/global
    - *B. Temporal*
        - - short-lived/long-term
5. ***Breakdown Mechanisms***
    - - none/biological/geological/chemical/radiative
6. ***Association with Economic Development***
    - - increasing/decreasing/inverted-U shaped with increasing income

Source: by author, after a suggestion by S. Moser, Clark University

Third, pollution varies according to its destination or *sink* within the biosphere, the atmosphere, hydrosphere, and/or lithosphere (the crust of the Earth).

Fourth, the effects or impacts of pollution vary both spatially and temporally. Spatially, carbon dioxide has a global effect; sulfur dioxide causes acid rain at the regional scale, often crossing international boundaries; particulates generally have a metropolitan scale effect; while heated water from power plants tends to cool off over a tiny distance. Temporally, the effects of different pollution types can range from short-lived (e.g., ground-level ozone, which is created and destroyed on a daily basis) to very long-term (e.g., plutonium, which will still be harmful thousands of years from now).

Fifth, there are a number of different natural mechanisms for breaking down human-produced materials, both biological and chemical.

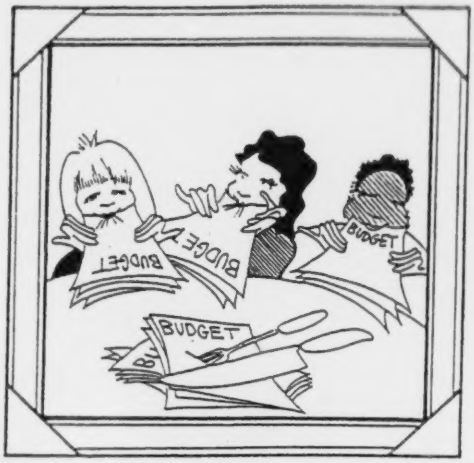
And finally, output of different kinds of materials also varies along the scale of economic development of the outputting society. Some forms of pollution, such as unclean drinking water, are a major problem in low-income countries but not as great a problem in high-income countries. Others, like solid waste and CO_2 production, tend to grow steadily in conjunction with income. Still others, like particulates (smoke and dust), tend to be nonexistent in nonindustrial societies, become a serious problem in the middle stages of development, and then decline in high-income countries as inexpensive technological solutions are implemented.

This last point directs our attention to one of the dominant themes of this module: the relation between wealth, resource (especially energy) consumption, the number of people consuming resources, and the local-to-global environmental impacts. Just as this look at pollution highlighted the immense variability that must be expected when trying to explain causes and impacts, so it is with energy consumption and its impacts on the environment. There are no single or simple answers that will hold water when we take a closer look!

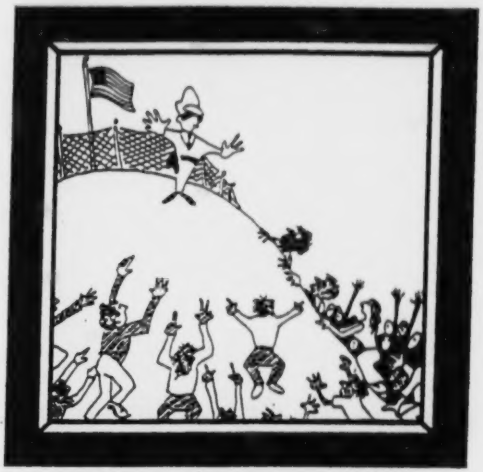
Population Frame Works, Inc.

—Traditional & Contemporary Designs—

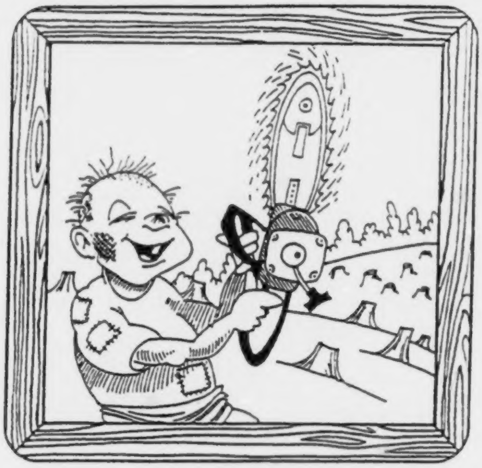
"We can frame any issue to make it look like a population problem"



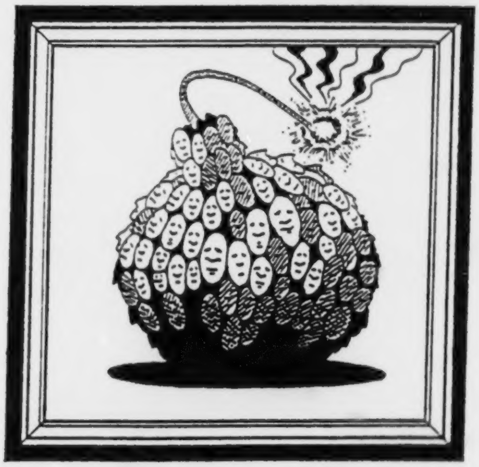
Single mothers on welfare are gobbling up the national budget!



Hordes of hungry immigrants are stampeding our borders!



Poor babies are destroying the rainforest!



Nuclear weapons? The arms trade? Fascism? Don't worry about them... The population bomb is our biggest national security threat!

Disinformation Our Specialty — Corporate Clients Welcome

Cartoon Concept: Betsy Hartmann · Design: David Caputo · Illustration: Rick Murnane – © 1995 Political Environments – May be reprinted with the preceding credit.

Taking notes that make sense -- even a year from now ...

As you work through the reading assignments for this and the following exercises, do not just read the articles, or just underline important passages. For understanding and remembering the arguments it is even more important to take notes on what you read. Taking concise yet comprehensive notes is a big step in preparing for classes and exams and to recall something you read or heard about.

If you are experienced in taking good notes, proceed to do so as you read your assigned materials. If you feel you could use some guidance in how to improve on this skill, follow the steps outlined below.

Articles that are written well have at least:

- ☐ a descriptive and/or provocative **title**,
- ☐ a compelling or at least an internally consistent **argument**,
- ☐ an apparent, intuitively logical, and hierarchical **structure** (look for subtitles),
- ☐ an obvious **paragraph separation and sequence**, and
- ☐ a clear, understandable **language** (including correct grammar and spelling, clear sentences, explanation for new or unusual terms, avoidance of unnecessary jargon and verbiage, etc.)

1 Gather the most obvious clues!

Browse through the article and note on a piece of paper its structure by writing down the title and all the subtitles of individual sections in the sequence in which they appear in the text. Indent all the subtitles that belong to the same logical section (to the same level in the hierarchy of importance) by the same amount so you know they are of similar importance and logically belong together. If there are no subtitles, you need to look at the text a bit more closely: is there a sequence of themes that the author(s) go through in the course of the text? If you can discern them, list them in the sequence in which they appear. (You may also group them later into logical classes if you can make out any.)

Example:

From limits to growth to global change: Constraints and contradictions...
    Global change -- the dominant issue
    Limits to growth to global change
    Why has global change become so prominent?
        Both science and ideology
        A rationale for environmentalists
        CFCs
        Media attraction
        International consensus
        Less intrusive change
        Opportunities for business
        A key factor in development debate
    Implications of global change as environmental ideology
        Disadvantages (list)
    Conclusions

2 **Put your mind's antennae out!**
Words in titles and subtitles, together with the logic behind the text's structure that becomes apparent when you take a little time to look over the outline just listed, tell you what to get your mind ready for. They are also the first hint as to what the author's main argument in the text is. These hints in effect are signals to your brain to activate all the pertinent knowledge you already have about a certain subject. The more conscious you become of these clues, the easier it will be for you to actually take in what someone writes. So looking back at the above example, **what do you expect the text to be about**? (Note that in this exercise we just make conscious, and more thoroughly so, what your brain does automatically, whenever you get new information!).

3 **Read the text (again)!**
If you have not read the article yet, do so now. Stop once in a while and recall what you thought the text would be about. Are your expectations met? (If they are not, you will probably be quite frustrated and most likely bored!)

4 **Note the main argument!**
Having had an expectation of the text and an actual read or two through it, what would you say is the main argument of the text? In other words: how would you describe to a friend what the gist of the article is?

5 **Concisely list the supporting arguments under each heading (or subtitle)!**
Every argument needs supporting arguments, data, and other evidence to be convincing. As you go once more through the text -- paragraph by paragraph -- list in keyword style or short sentences what the author(s) have to offer for supporting evidence an arguments. If you can't decide what is important and what is not (and thus should be omitted from this listing), ask yourself whether you found it important to know or mention this particular item to understand the logic behind the argument. If not, leave it out! You are most likely to forget everything that is not essential to the argument anyway.

6 **Check whether it makes sense!**
Once you're through with Steps 1-5, look over your notes once again and see whether they make sense. (The best test is really three days after taking the notes, i.e. when you're already somewhat removed from having read the article. If they still makes good sense, you took good notes!) If you feel as if you lost the thread of the argument somewhere, then fill in the blanks. Also compare the length of your notes with the length of the article: if your notes are as long as the original article, you simply paraphrased the text. By definition notes are short and never as prosaic as an essay!

World Map

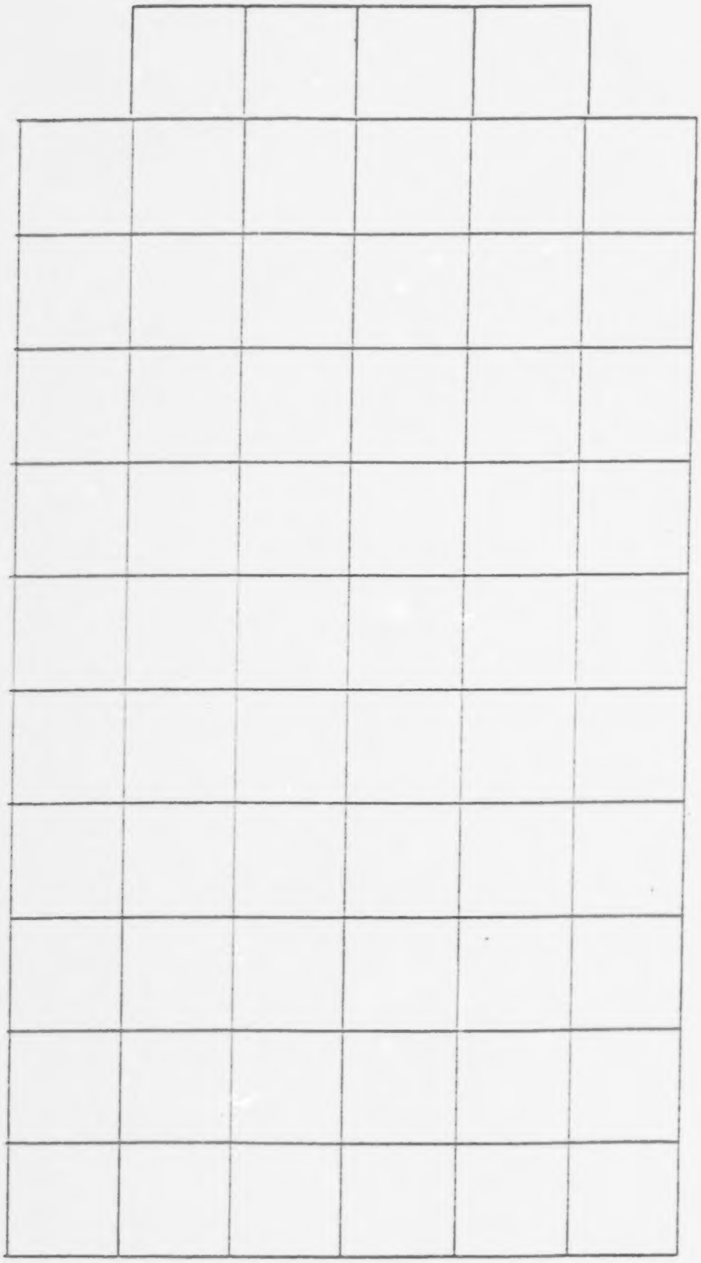
Global Distribution of Various Socioeconomic Indicators

The following attributes were compiled from the *World Resources Database*. It is difficult to obtain recent, aggregated, and compatible data. The module authors decided that for demonstrative purposes, the few variables shown below would suffice. To get continental totals, multiply the per capita value by the continental population data provided in the Unit 1 Instructor's Guide to Activities.

Continent	Commercial Energy Consumption Per Capita Gigajoules (1991)	Per Capita CO_2 Emissions Metric Tons (1991)	Auto Registrations Per 1,000 Population (1990)	Crude Birth Rate Per 1,000 Population (1990)	Hectares Cropland Per 1,000 Population (1991)
Africa	12	1.03	21.64	44.5	274.41
Asia	25	2.11	31.68	27.5	144.09
No./Central America	243	13.59	554.88	19.2	687.09
Europe	134	8.20	439.55	12.8	270.31
Oceania	161	11.24	85.74	19.5	1788.29
So. America	32	2.00	84.04	26.8	384.97
Former USSR	193	12.31			

Source: Compiled from *World Resources Database*. 1994. Washington, DC: World Resources Institute.

Critters in a Jar



Definition of Energy

Energy is the ability to do work. Energy in different forms allows us to do different kinds of work.

Examples: Electricity (form) produced from coal (source) enables me to cook my food (work). With gasoline (form) made from petroleum (source) I can drive to school (work).

Measures of Energy

Calories	1 calorie is the amount of energy required to raise the temperature of 1 gram of water by 1 degree centigrade.
BTU	British Thermal Unit. 1 BTU is the non-metric equivalent of the calorie: the amount of energy required to raise the temperature of 1 pound of water by 1 degree Fahrenheit. (1 BTU = 252 calories.)
Quads	The US Department of Energy measures total energy in *Quads*, which is equal to 1 quadrillion BTU, i.e., 10^{15} or 1,000,000,000,000,000 BTU (used in this module).
toe	Tons of oil equivalent, a measure commonly used in international statistics. (1 toe = 39,680,000 BTU.) Conversion factors are estimated for converting tons of coal, tons of gas, the energy of falling water, etc. to their equivalent amount of tons of oil, i.e., how much oil would be required to replace these others. *"mtoe"* (also used here) stands for "million tons of oil equivalent."

Definitions of Energy Use

It is important to distinguish various energy use definitions that apply at different stages of the economic process in order to follow energy through the economy and to see where energy use is inefficient and reducible.

☆***Primary (indigenous) energy production*** (PEP) is the amount of energy produced within a country. "Primary" refers to the fact that the energy is in its raw state, i.e., not converted to a different form such as electricity, gasoline, etc. "Production" refers to the fact that it is produced domestically, not imported. "Indigenous" is sometimes added to clarify that it is *domestic* production.

☆***Total primary energy supply*** (TPES) is domestic production plus imports, minus exports, the grand total of what goes *in* to the domestic energy system.

☆***Total final consumption*** (TFC) is the amount of energy that is used by the *final consumers* of the energy, i.e., not by power plants or oil refineries, but by the end users of electricity and gasoline.

☆***Energy service demand*** (ESD), also known as *useful energy,* is the amount of work performed by the consumed energy.

Examples: (1) Electricity may be used for a pump motor. In this case, ESD refers to how much water was moved how far uphill, not how much electricity was consumed by the pump. (2) We can distinguish between the amount of energy consumed by a light fixture (TFC) and the energy content of the actual light produced (ESD). Since no machine is 100% efficient at converting energy to work, energy service demand is always smaller than total final consumption.

Elasticity

Elasticity means **responsiveness** or **sensitivity.** Economists use this term to describe the **rate of change of one thing compared to the rate of change of another**. Or -- in terms of a graphic example -- a rubber band is elastic in that it elongates when you pull on it. A piece of wood under the same kind of treatment is very inelastic.

In economics, a common term is **price elasticity**. Applied to energy consumption, consider the following example: *Demand of oil is said to be inelastic with respect to price because when the price goes up, demand usually does not fall very much.* Why?

Reasons for price inelasticity:
- there are few substitutes for the good
- the good is not a luxury item, but a necessity
- the good makes up a small part of our budgets, which means that a price increase doesn't matter much to us.

Income elasticity refers to the responsiveness of energy demand to changes in income. At the national level , our national income is measured as Gross Domestic Product (GDP), the value of all final (i.e., not intermediate) goods and services sold during one year.

Income elasticity of energy demand is therefore defined as:

$$\frac{\Delta \text{TPES}}{\Delta \text{GDP}}$$

Energy Intensity

Energy intensity is the **ratio of energy use to gross domestic product**, i.e.:

$$\frac{\text{TPES}}{\text{GDP}}$$

It can be used to compare the energy efficiencies of different countries.

Technological Change

Technological change is the **switch** (over a period of time) **from one technology (including inputs, machinery and the necessary know-how) to another technology**. Technological change or innovation is often associated with notions of increased profitability, decreased need for human labor, more efficient use of resources or energy, even improvement of the quality of life etc.

Examples:
☆ fast computers in place of manual typewriters and calculators;
☆ improvements in car motors that increase gas mileage.

Structural Change

Structural change refers to changes in the structure of an entity; with respect to economics it refers to the **sectoral changes in the national economy**. Over time, the proportional shares of the primary, secondary, and tertiary (and quaternary) sectors of an economy do not stay constant. These changes reflect societal changes and are expressed in a country's economy.

Example:
☆ more people working in services (restaurants, stores, banks, etc.) and fewer people working in mines or on farms.

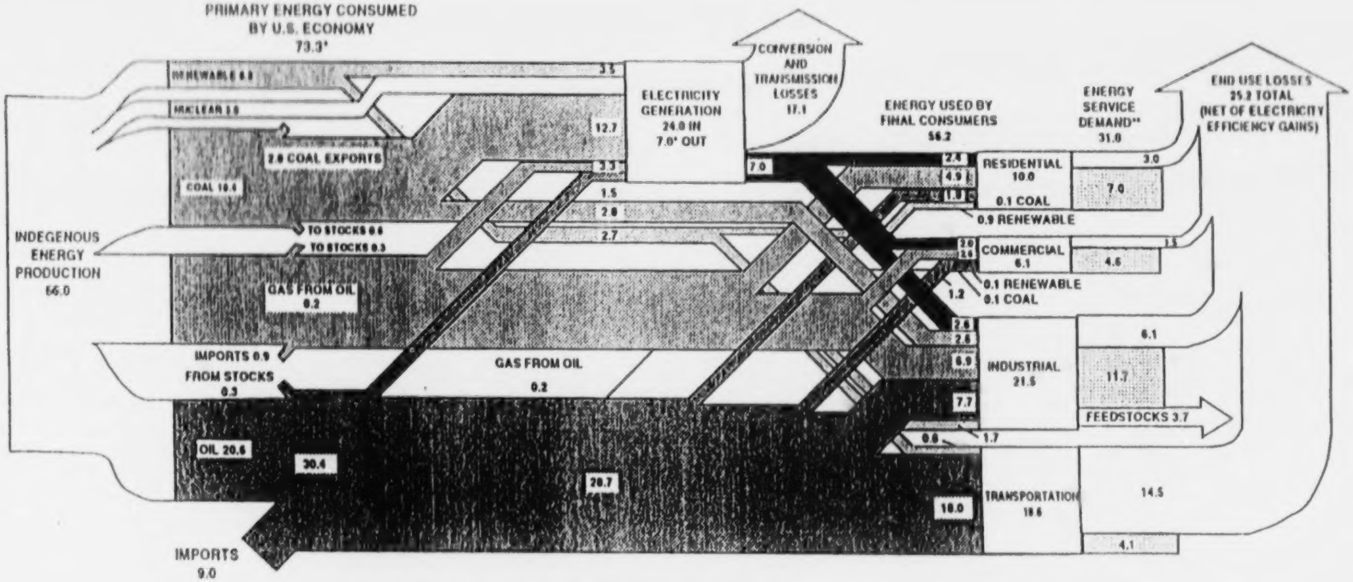
Energy Use in Our Daily Lives

The following list contains examples of when and where we use energy in our daily lives, where it comes from and where it goes. It is certainly not an exclusive list, especially since energy use is hidden in the products we use (*e.g.*, a soda aluminum can, a plastic bottle, virgin paper); so don't feel restricted to these examples. Everything on Earth that moves, works, or changes requires some form of energy, even if that is not always immediately obvious. As you write your own energy log for one day--either chronologically or topically ordered--recall the definition of energy you heard in class, and include in your report energy sources, the forms in which you use energy, what you use it for, including goods for which energy was used to produce them, and what some of the byproducts or environmental impacts of this energy use are.

ENERGY SOURCE	ENERGY	WORK PERFORMED	WASTE/IMPACTS
NON-RENEWABLES			
Fossil fuels			
Coal	Electricity	Lighting, appliances, computers, some cooking & heating, others	CO_2, SO_2 emissions, mine run-off
Petroleum	Gas for cars	Driving my car, transporting	CO_2, SO_2, NO_x emissions, oil spills
	Oil for furnaces	Heating	
	Fertilizers	Growing more food, bigger vegetables and fruit	biodegradable waste
Natural gas	Gas for furnaces	Heating water/rooms	CO_2, CH_4 and other emissions
	Gas for cooking	Boiling water, making tea	
Nuclear fuel	Electricity	Lighting, appliances, computers, some cooking & heating, others	Radioactive waste, heat emission
RENEWABLES			
Water	Electricity	Same	Habitat flooding, disruption of migration
Sun/solar energy	Electricity or Direct Heating	Same, or space and water heating	Land development, manufacture of solar cells, mirrors
Wind	Electricity or Kinetic energy	Same, or pumping water	Land development, visual impacts
Biomass	Wood	Heating a house	CO_2, SO_2, CH_4 etc. emissions
	Gas >> electricity	Cooking breakfast	
	Food	Nourishing animals & people	feces and other biodegradable waste
	Grain >> methanol	Driving a car	

1982 Energy Flow Diagram

U.S ENERGY SOURCES AND USES IN 1982
(Quadrillion Btus)


PRIMARY ENERGY CONSUMED BY U.S. ECONOMY 73.3*
RENEWABLE 6.8
NUCLEAR 3.0
2.8 COAL EXPORTS
COAL 18.6
INDEGENOUS ENERGY PRODUCTION 66.0
TO STOCKS 0.6
TO STOCKS 0.3
GAS FROM OIL 0.2
IMPORTS 0.9
FROM STOCKS 0.3
GAS FROM OIL 0.2
OIL 20.6
30.4
20.7
IMPORTS 9.0
3.5
12.7
3.3
1.5
2.8
2.7
ELECTRICITY GENERATION 24.0 IN 7.0* OUT
CONVERSION AND TRANSMISSION LOSSES 17.1
7.0
ENERGY USED BY FINAL CONSUMERS 56.2
2.4
4.9
1.8
RESIDENTIAL 10.0
0.1 COAL
0.9 RENEWABLE
2.0
2.6
COMMERCIAL 6.1
1.2
0.1 RENEWABLE
0.1 COAL
2.6
2.6
6.9
INDUSTRIAL 21.5
7.7
0.8
1.7
10.0
TRANSPORTATION 18.6
ENERGY SERVICE DEMAND** 31.0
3.0
7.0
1.5
4.6
6.1
11.7
FEEDSTOCKS 3.7
14.5
4.1
END USE LOSSES 25.2 TOTAL (NET OF ELECTRICITY EFFICIENCY GAINS)

* INCLUDES 0.1 QUADS OF IMPORTED HYDROELECTRIC POWER

** INCLUDES 3.7 QUADS OF ENERGY RESOURCES USED ASFEEDSTOCKS FOR THE MANUFACTURER OF NON-ENERGY MATERIALS, BASED ON END-USE EFFICIENCIES FROM 1980 BROOKHAVEN DATA.

Source: U.S. Energy Information Administration. 1983. *Annual Energy Review 1982*. Washington, D.C.: U.S. Department of Energy.

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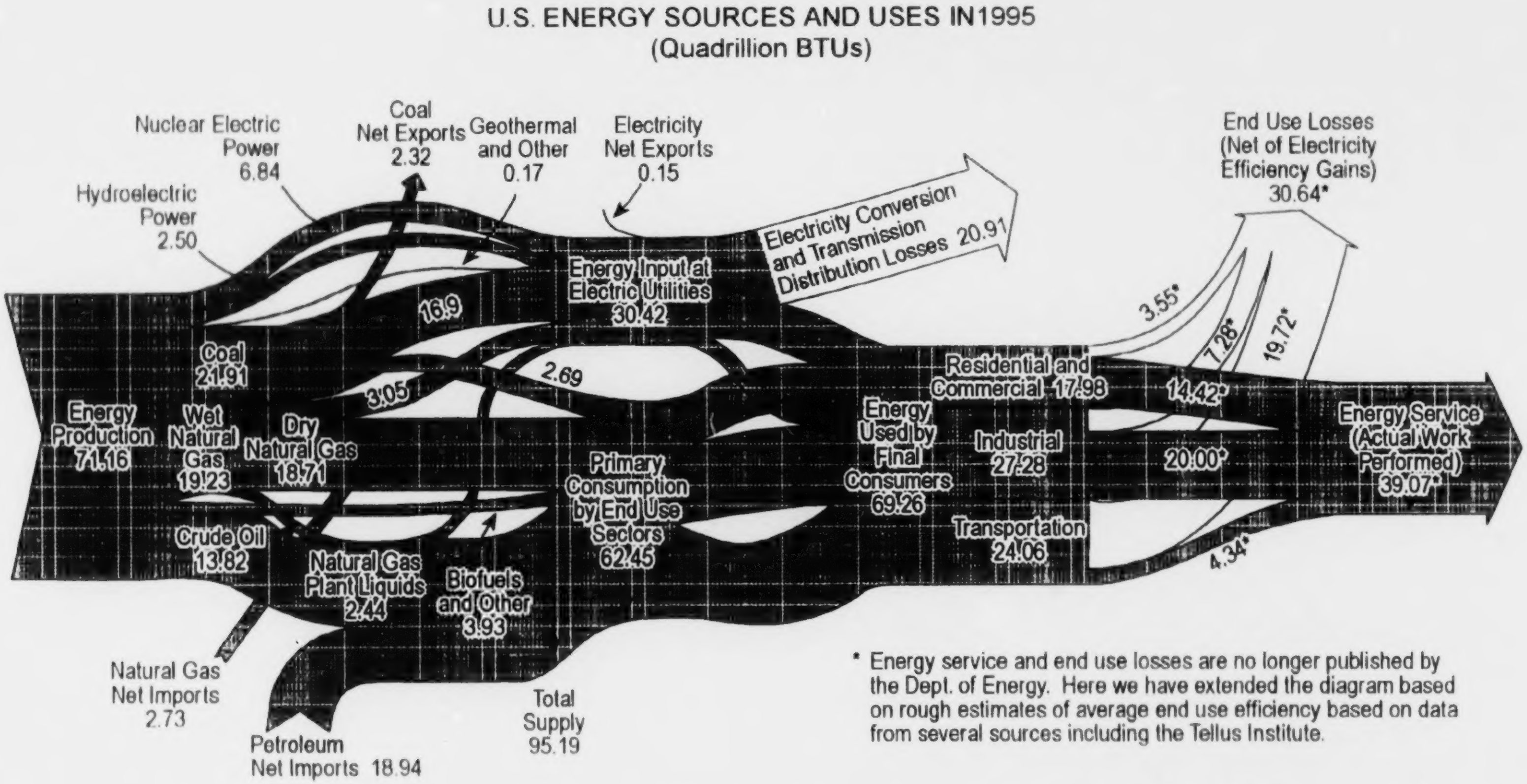
1995 Energy Flow Diagram


U.S. ENERGY SOURCES AND USES IN1995
(Quadrillion BTUs)
Nuclear Electric Power 6.84
Coal Net Exports 2.32
Geothermal and Other 0.17
Electricity Net Exports 0.15
Hydroelectric Power 2.50
Electricity Conversion and Transmission Distribution Losses 20.91
End Use Losses (Net of Electricity Efficiency Gains) 30.64*
Energy Input at Electric Utilities 30.42
16.9
3.55*
7.28*
19.72*
Coal 21.91
2.69
3.05
Residential and Commercial 17.98
14.42*
Energy Production 71.16
Wet Natural Gas 19.23
Dry Natural Gas 18.71
Energy Used by Final Consumers 69.26
Industrial 27.28
20.00*
Energy Service (Actual Work Performed) 39.07*
Primary Consumption by End Use Sectors 62.45
Crude Oil 13.82
Transportation 24.06
4.34*
Natural Gas Plant Liquids 2.44
Biofuels and Other 3.93
Natural Gas Net Imports 2.73
Petroleum Net Imports 18.94
Total Supply 95.19

* Energy service and end use losses are no longer published by the Dept. of Energy. Here we have extended the diagram based on rough estimates of average end use efficiency based on data from several sources including the Tellus Institute.

Source: Adapted from U.S. Energy Information Administration. 1996. *Annual Energy Review 1995.* Washington, D.C.: U.S. Department of Energy. Note: The original diagram found in source has been altered by the module author.

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DOE Table 2.13: Age Distribution of Stock and Potential Annual Energy Savings of Selected Appliances, 1990

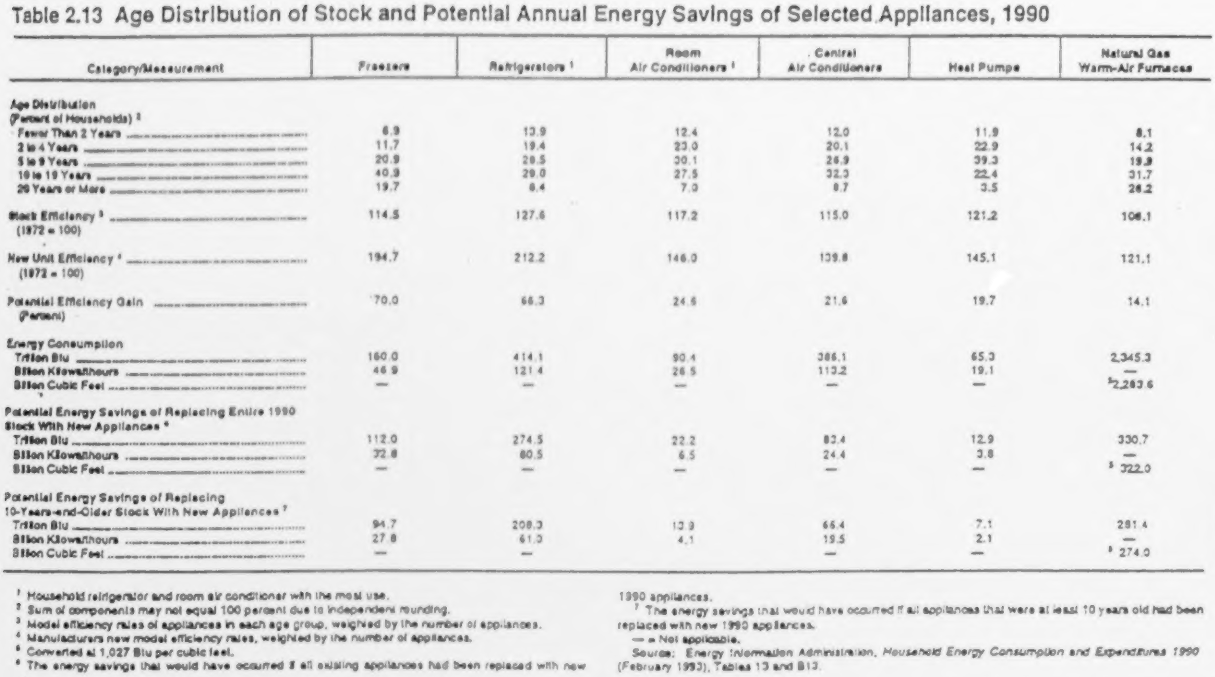

Table 2.13 Age Distribution of Stock and Potential Annual Energy Savings of Selected Appliances, 1990

Category/Measurement	Freezers	Refrigerators [1]	Room Air Conditioners [1]	Central Air Conditioners	Heat Pumps	Natural Gas Warm-Air Furnaces
Age Distribution (Percent of Households) [2]						
Fewer Than 2 Years	6.9	13.9	12.4	12.0	11.9	8.1
2 to 4 Years	11.7	19.4	23.0	20.1	22.9	14.2
5 to 9 Years	20.9	28.5	30.1	26.9	39.3	19.9
10 to 19 Years	40.9	29.0	27.5	32.3	22.4	31.7
20 Years or More	19.7	8.4	7.0	8.7	3.5	26.2
Stock Efficiency [3] (1972 = 100)	114.5	127.6	117.2	115.0	121.2	106.1
New Unit Efficiency [4] (1972 = 100)	194.7	212.2	146.0	139.8	145.1	121.1
Potential Efficiency Gain (Percent)	70.0	66.3	24.6	21.6	19.7	14.1
Energy Consumption						
Trillion Btu	160.0	414.1	90.4	386.1	65.3	2,345.3
Billion Kilowatthours	46.9	121.4	26.5	113.2	19.1	—
Billion Cubic Feet	—	—	—	—	—	[5]2,283.6
Potential Energy Savings of Replacing Entire 1990 Stock With New Appliances [6]						
Trillion Btu	112.0	274.5	22.2	83.4	12.9	330.7
Billion Kilowatthours	32.8	80.5	6.5	24.4	3.8	—
Billion Cubic Feet	—	—	—	—	—	[5] 322.0
Potential Energy Savings of Replacing 10-Years-and-Older Stock With New Appliances [7]						
Trillion Btu	94.7	208.3	13.9	66.4	7.1	281.4
Billion Kilowatthours	27.8	61.0	4.1	19.5	2.1	—
Billion Cubic Feet	—	—		—	—	[5] 274.0

[1] Household refrigerator and room air conditioner with the most use.
[2] Sum of components may not equal 100 percent due to independent rounding.
[3] Model efficiency rates of appliances in each age group, weighted by the number of appliances.
[4] Manufacturers new model efficiency rates, weighted by the number of appliances.
[5] Converted at 1,027 Btu per cubic feet.
[6] The energy savings that would have occurred if all existing appliances had been replaced with new 1990 appliances.
[7] The energy savings that would have occurred if all appliances that were at least 10 years old had been replaced with new 1990 appliances.

— = Not applicable.

Source: Energy Information Administration, *Household Energy Consumption and Expenditures 1990* (February 1993), Tables 13 and B13.

Source: U.S. Energy Information Administration. 1994. *Annual energy review 1993.* Washington, DC: U.S. Department of Energy.

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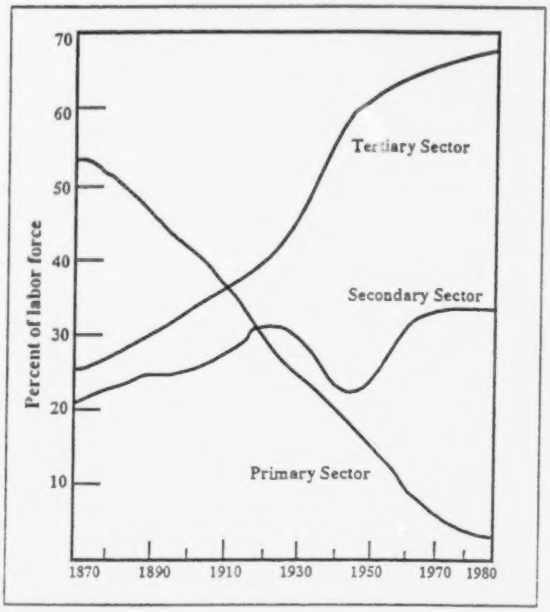
The Changing Structure of the US Economy, 1870-1990

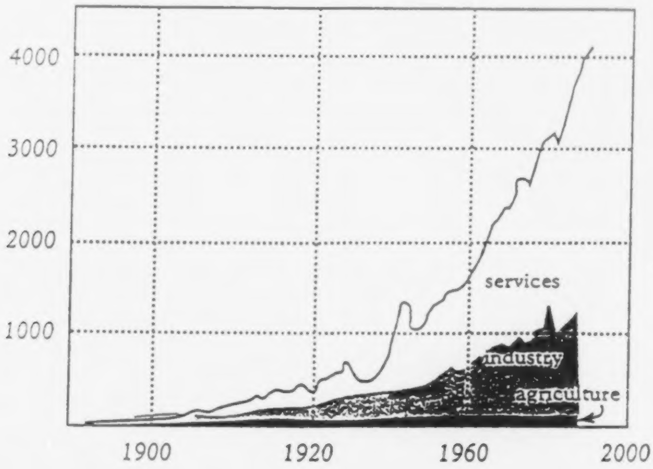


Source: Wheeler, J.O. and P.O. Muller. 1981. *Economic geography*. New York: Wiley, p. 52. Reprinted by permission of John Wiley & Sons, Inc.

The changing percentage of the U.S. labor force in the major economic sectors is a measure of the changes in levels of economic development the country has experienced.

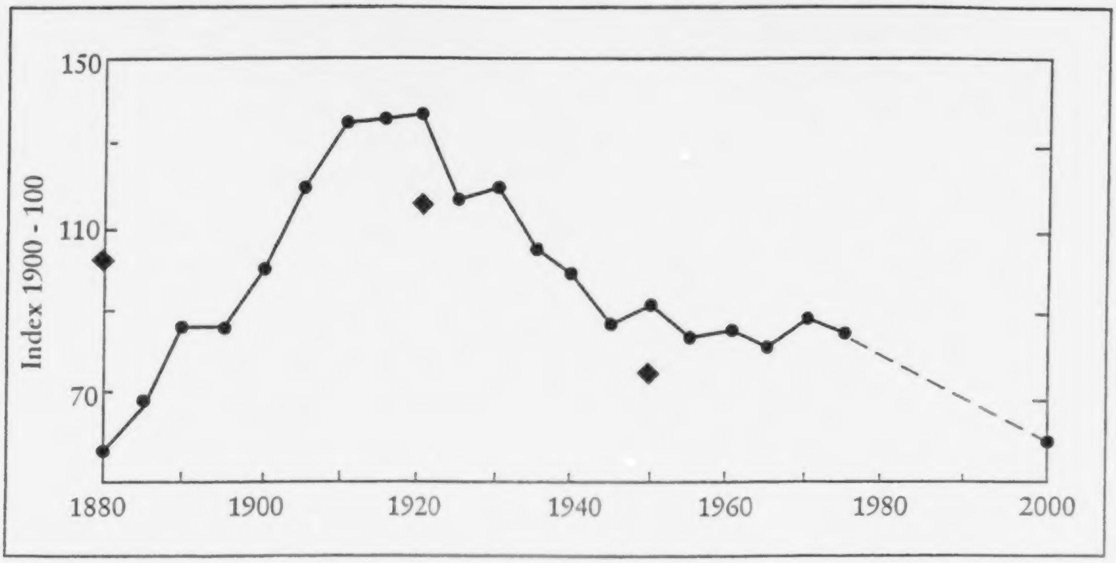
U.S. GNP BY SECTOR

Billions of 1982 dollars by year



Source: Meadows, D.H., D.L. Meadows, and J. Randers. 1992. *Beyond the limits*. Post Mills, VT: Chelsea Green Publishing, p. 36. Reprinted with the permission of Chelsea Green Publishing Company.

U.S. Energy Consumption per $ of GNP, 1880-1975



Source: Schurr, S.H., J. Darmstadter, H. Perry, W. Ramsey, and M. Russell. 1979. *Energy in America's future.* Washington, DC: Resources for the Future. Reprinted with the permission of Resources for the Future.

Note: The diamonds on the graph show estimates of the energy intensity if firewood had been included. Firewood is a non-commercial energy source since it is free and uncounted in economic statistics. The main graph shows only commercial energy.

DOE Table 10.1: Renewable Energy Consumption Estimates in the US, 1990-1995

Table 10.1b Renewable Energy Consumption by Sector, 1990-1995
(Quadrillion Btu)

Year	Residential and Commercial			Industrial 1						Transportation	Electric Utility1					Total
	Biofuels	Solar 2	Total	Biofuels	Geothermal	Conventional Hydroelectric3	Solar	Wind	Total	Biofuels 4	Biofuels	Geothermal5	Conventional Hydroelectric 36	Solar and Wind	Total	
1990	0.581	0.060	0.641	R1.948	R0.146	R0.082	R0.007	R0.024	R2.206	0.082	0.021	0.192	R3.020	(s)	R3.234	R6.163
1991	0.613	0.060	0.673	R1.943	R0.162	R0.083	R0.008	R0.027	R2.223	0.065	0.021	0.185	R3.098	(s)	R3.304	R6.265
1992	0.645	0.060	0.705	R2.042	R0.179	R0.097	R0.008	R0.030	R2.357	0.079	0.022	0.188	R2.755	(s)	R2.965	R6.106
1993	R0.592	0.060	R0.652	R2.084	R0.204	R0.118	R0.009	R0.031	R2.446	0.088	0.020	0.177	R3.019	(s)	R3.217	R6.403
1994	R0.582	0.060	R0.642	R2.152	R0.212	R0.136	R0.008	R0.036	R2.541	R0.098	0.020	0.170	R2.822	(s)	R3.012	R6.296
1995E	0.641	0.064	0.705	2.178	0.244	0.153	0.010	0.041	2.625	0.105	0.017	0.118	3.309	(s)	3.444	6.879

1 Generation of electricity by cogenerators, independent power producers, and small power producers is included in the industrial sector, not the electric utility sector.

2 The solar energy number of 0.06 quadrillion Btu for residential and commercial use is calculated by presuming an overall efficiency of 50 percent for all three categories of solar thermal collectors (low temperature, medium temperature, and high temperature), a 1,500-Btu per square foot average daily insolation, and the potential thermal energy production from the 219 million square feet of solar thermal collectors produced since 1974. This is a simplified approach since low-temperature and high-temperature collectors have been rated at more than 50 percent efficient and medium-temperature collectors are generally less than 50 percent efficient.

3 Hydroelectricity generated by pumped storage is not included in renewable energy.

4 Ethanol blended into motor gasoline.

5 Includes electricity imports from Mexico that are derived from geothermal energy.

6 Includes electricity net imports from Canada that are derived from hydroelectric power.

R=Revised data. E=Estimate. (s)=Less than 0.5 trillion Btu.

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Renewable Energy Annual 1995 (December 1995).

Source: U.S. Energy Information Administration. 1995. *Annual energy review 1995.* Washington, DC: U.S. Department of Energy.

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DOE Table F: US Solar Thermal Collector Shipments by Market and Type, 1994-95

Table F. Shipments of Solar Thermal Collectors by Market and Type, 1994 and 1995
(Thousand Square Feet)

Market Sector	Low-Temperature Liquid/Air Metallic and Nonmetallic	Med Temp Air	Medium Temp Liquid ICS/ Thermosiphon	Medium Temp Liquid Flat-Plate (Pumped)	Medium Temp Liquid Evacuated Tube	Medium Temp Liquid Concentrator	High Temperature Parabolic Dish/Trough	1995 Total	1994 Total
Residential	6,192	13	150	610	1	0	0	6,966	7,026
Commercial	552	6	4	41	(s)	0	1	604	583
Industrial	69	0	0	12	(s)	0	0	82	16
Utility	0	0	0	0	(s)	(s)	9	9	2
Other(a)	0	0	2	1	(s)	0	3	6	0
Total	6,813	18	156	664	1	(s)	13	7,666	7,627
End Use									
Pool Heating	6,731	6	0	26	(s)	0	0	6,763	6,813
Hot Water	11	7	108	627	1	(s)	0	755	790
Space Heating	70	5	48	9	0	0	0	132	19
Space Cooling	0	0	0	0	(s)	0	1	1	0
Combined Space & Water Heating	(s)	0	0	2	0	0	0	2	4
Process Heating	0	0	0	0	(s)	0	0	(s)	0
Electricity Generation	0	0	0	0	(s)	0	9	10	1
Other	0	0	0	0	0	0	2	2	(s)
Total	6,813	18	156	664	1	(s)	13	7,666	7,627

(a) = Other includes shipments of solar thermal collectors for other uses such as cooking foods, water pumping, water purification, desalinization, distilling, etc.
(s) = Less that 500 square feet.
ICS = Integral Collector Storage.
Note: Totals may not equal sum of components due to independent rounding.

Source: U.S. Energy Information Administration. 1996. *Annual energy review 1995*. Washington, DC: U.S. Department of Energy.

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DOE Table G: US Photovoltaic Cell and Module Shipments and Trade, 1985-1995

Table 3. Number of Companies and Total Shipments of Photovoltaic Cells and Modules, 1985-1995
(Peak Kilowatts)

Year	Number of Companies	Photovoltaic Cell and Module Shipments Total	Import	Export
1985(a)	15	5,769	285	1,670
1986(a)	17	6,333	678	3,109
1987(a)	17	6,850	921	3,821
1988(a)	14	9,676	1,453	5,358
1989(a)	17	12,825	826	7,363
1990(a)	(b)19	(b)13,837	1,398	7,544
1991(a)	23	14,939	2,059	8,905
1992(a)	21	15,583	1,602	9,823
1993(a)	19	20,951	1,767	14,814
1994(a)	22	26,077	1,960	17,714
1995(a)	24	31,059	1,337	19,871

(a) = Does not include shipments of cells and modules for space/satellite applications

(b) = Includes imputed data for one nonrespondent, which exited the industry during 1990.

Note: Total shipments as reported by respondents includes all domestic and export shipments and may include imports that subsequently were shipped to domestic or foreign customers.

Source: U.S. Energy Information Administration. 1996. *Annual energy review 1995*. Washington, DC: U.S. Department of Energy.

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DOE Table K: US Photovoltaic Cell and Module Shipments by Market, End Use, and Type, 1994-95

Table K. Shipments of Photovoltaic Cells and Modules by Market Sector, End Use, and Type, 1994 and 1995

Type	Crystalline Silicon	Thin-Film Silicon	Concentrator Silicon	Other	1995 Total	1994 Total
Market Sector						
Industrial	6,981	217	0	0	7,198	6,855
Residential	6,226	31	15	0	6,272	6,632
Commercial	7,784	286	30	0	8,100	5,429
Transportation	2,140	243	0	0	2,383	2,174
Utility	3,724	28	7	0	3,759	2,364
Government (a)	1,979	20	1	0	2,000	2,114
Other (b)	906	441	0	0	1,347	510
Total	29,740	1,266	53	0	31,059	26,077
End Use						
Electricity Generation						
Grid Interactive	4,423	157	5	0	4,585	2,296
Remote	7,993	222	18	0	8,233	9,253
Communication	5,140	14	0	0	5,154	5,570
Consumer Goods	1,013	12	0	0	1,025	3,239
Transportation	4,049	154	0	0	4,203	2,128
Water Pumping	2,680	47	0	0	2,727	1,410
Cells/Modules to OEM (c)	2,622	565	0	0	3,188	1,849
Health	775	1	0	0	776	79
Other (d)	1,045	95	30	0	1,170	254
Total	29,740	1,266	53	0	31,059	26,077

(a) = Includes Federal, State, and local governments, excluding military.
(b) = Includes shipments that are manufactured for private contractors for reseasrch and development projects.
(c) = OEM is original equipment manufacturers
(d) = Other uses include shipments of photovoltaic cells and modules for uses such as coooking food, desalinization, distilling, etc.
W = Data withheld to avoid disclosure.
Note: Total may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Form EIA-63B, 'Annual Photovoltaic Module/Cell Survey.'

Source: U.S. Energy Information Administration. 1996. *Annual energy review 1995*. Washington D.C. U.S. Department of Energy.

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Table 4.1a: Impacts of U.S. Gasoline Consumption 1960-95

	P ×	A_1 ×	A_2 ×	T_1	=	Resource Throughput ×	Emissions rate	=	I_1
Year	Persons ×	Cars/Person ×	Mile/Car ×	Gal/Mile ×	=	Gallons ×	CO_2/Gal.	=	lbs. CO_2
1960	180 mil. ×	.34 ×	9,446 ×	1/14.3 ×	=	_______ ×	19.01	=	_______
1995	265 mil. ×	.59 ×	11,838 ×	1/19.8 ×	=	_______ ×	19.01	=	_______

	P ×	A_1 ×	A_2 ×	T_1 ×	=	Resource Throughput ×	T_2 ×	Emissions rate	=	I_2
Year	Persons ×	Cars/Person ×	Mile/Car ×	Gal/Mile ×	=	Gallons ×	%Untreated	NO/Gal.	=	lbs. NO
1960	180 mil. ×	.34 ×	9,446 ×	1/14.3 ×	=	_______ ×	1.0 ×	.12	=	_______
1995	265 mil. ×	.59 ×	11,838 ×	1/19.8 ×	=	_______ ×	.38 ×	.12	=	_______

T_1 = Technology factor for resource use efficiency (miles per gallon).
T_2 = Technology factor for pollution control devices (catalytic converters).

Note: Includes only household-owned vehicles, not business-owned vehicles, but does include minivans and light trucks.

Table 4.1b: Impacts of Coal Consumption for Power Generation: U.S. and China

	P ×	A ×	T_1 ×	T_2	=	Resource Throughput ×	Emissions Rate	=	I_1
	Persons ×	kWh/ Person ×	Tons/kWh ×	% From Coal	=	Coal Tons ×	CO_2/Ton	=	Tons CO_2
USA	265 m. ×	12781 ×	.000470 ×	.52 ×	=	_______ ×	2.10	=	_______
China	1218 m ×	810×	.000591 ×	.81 ×	=	_______ ×	2.10	=	_______

	P ×	A ×	T_1 ×	T_2	=	Resource Throughput ×	T_3 ×	T_4 ×	Emissions Rate	=	I_2
	Persons ×	kWh/ Person ×	Tons/kWh ×	% From Coal ×	=	Coal Tons ×	%Untreated by Wash ×	%Untreated by Scrub ×	SO_2/Ton	=	Tons SO_2
USA	265 m. ×	12781 ×	.000470 ×	.52 ×	=	_______ ×	.875 ×	.775 ×	.0225	=	_______
China	1218 m ×	810 ×	.000591 ×	.81 ×	=	_______ ×	98 ×	1.0 ×	.0225	=	_______

T_1 = Technology factor for resource use efficiency (conversion from coal to electricity).
T_2 = Technology factor for type of resource used (reliance on coal for power generation).
T_3 = Technology factor for pollution control (coal washing)
T_4 = Technology factor for pollution control (flue gas desulfurization, or "scrubbers")

Sources for data in Supporting Material 4.1a & b.
U.S. Department of Energy. 1996. *Annual energy review 1995.* DOE/EIA-0384(95). Washington, D.C.: U.S. Government Printing Office.
Lester R. Brown (ed). 1989. *State of the world, 1989.* New York: W.W. Norton.
World Bank. 1995. ***Investment strategies for China's coal and electricity delivery system.*** Report No. 12687-CHA. Washington, D.C.: World Bank
Ratick, Samuel and Michael Kuby. 1987. Regional assessment of coal utilization technologies using mathematical programming. *Applications of Management Science* 5: 155-195.
Population Reference Bureau. 1996. *1996 World population data sheet.* Washington, D.C.: PRB.
State Statistical Bureau. 1995. *Statistical yearbook of China 1995.* Beijing: State Statistical Bureau.

Material Throughput

Meadows et al. (1992) define material throughput as: "the flow of energy and/or materials from the original sources, through the system (where it may be transformed), and out to the ultimate sinks [such as air, water and soil]." Some environmental scientists argue that environmental impacts are proportional to the latter half of "throughput" (i.e., pollution).

The IPAT formula is a way to quantify the factors that contribute to throughput.

☆ Ehrlich/Holdren originally argued that Impact was strictly a function of Population (P):

$$\mathbf{I = P \times F(P)}$$

with:
I = negative environmental impact
P = population
F = per capita impact (as a non-linear function of P)

☆ Later, after Commoner et al. pointed out the importance of technological change, the IPAT formula emerged:

I	=	P	×	A	×	T
Level of pollution	=	population size	×	per capita consumption	×	environmental impact per unit of production

☆ Recently The World Bank put a more economic spin on IPAT:

Quality of Environment	=	scale of economy (P × A)	×	output structure of the economy	×	input-output efficiency of each sector	×	env. damage/ unit of output

Population and Environment Worksheet

Make as many copies of this worksheet as you think you might need (at least six, one for each country) for the information you will compile on the environment/population/economy situation in the countries of your choice. After you've decided with the other members of your country group for which indicators/variables to get data, go to the relevant data sources (look them up in previous sections of this module, ask your team members or your instructor!), and write down the information you find in the respective columns below. Don't forget to write down data for two different years -- as you decided in your group. Then meet with the other group members and compare notes!

Country____

Initial Year	**State of the Environment Data**	**Population Data**	**Economic Data**	**Level of Technological Development Data**
Latest Year				

Appendices

Appendix A: Teaching Aids, Additional References, and Contact Addresses

1. In Hyden, Kates, and Turner's (1993a+b) work (cited in the references) -- esp. the first of the two chapters (1993a) -- there are a number of useful teaching aids. The discussed *field study cases* in these authors' work provide excellent supplementary readings for students. The first chapter is a good introduction to the *intellectual history of the concept of intensification* and is also an excellent discussion of the *Boserupian, neo-Marxist, neo-Malthusian, and neo-liberal economics* schools of thought.

2. A number of excellent teaching aids, films, policy papers, and magazines have been produced by *The Population Reference Bureau*. They can be contacted at:

   Population Reference Bureau
   1875 Connecticut Ave. N.W., Suite 520
   Washington, D.C. 20009
   Tel. 202-483-1100
   E-mail: popref@igc.apc.org

3. An excellent discussion of the linkages among population, wealth, and the environment is the recent report by Robert Engelman of Population Action International (1994) entitled: *Stabilizing the atmosphere: population, consumption, and greenhouse gases.* Note particularly Section II: "Considering population's role" pp. 17-24. The paper is very "user-friendly" -- with many charts, graphs, and data that are excellent resources for students or faculty. This resource guide and others on land and water resources can be obtained free of charge from:

   Population Action International
   1120 19th Street, NW, Suite 550
   Washington, D.C. 20036.
   Tel. 202-659-1833
   FAX 202-293-1795
   E-mail: popact@igc.apc.org.

4. For more information and publications on carrying capacity, contact the *Carrying Capacity Network* at:

    1325 G Street, NW Suite 1003
    Washington, D.C. 20005-3104
    Tel. 202-879-3044 or 1-800-466-4866

5. The Committee on Women, Population, and the Environment publishes a Newsletter called *Political Environments.* This publication gives voice to one of the more marginalized approaches to understanding the population-environment interface. The Committee is primarily opposed to "statements and analyses that single out population size and growth as a primary cause of global environmental degradation" (*Political Environments (Summer 1995)*, 2: 40). The feminist perspective(s) offered in this newsletter are refreshing, important, and provocative counter-arguments to mainstream thinking, and interesting additions to an in-class discussion of controversial national and international population-environment issues.

    For Newsletter requests:
    Committee on Women, Population, and the Environment
    c/o Population and Development Program/SS
    Hampshire College
    P.O. Box 5001
    Amherst, MA 01002
    Tel.: (413) 582-5506
    Fax.: (413) 582-5620
    E-mail: cwpe@igc.apc.org

    For further information on the Committee's work, contact the CWPE Coordinator:
    Manjari Mehta
    c/o Boston Women's Health Book Collective
    P.O. Box 192
    Somerville, MA 02144
    Tel.: (617) 625-2622
    Fax.: (617) 625-0294

Appendix B: Text Books and Additional References

General college population geography texts available include:

- Peters, Gary L. 1993. *Population geography: Problems, concepts, and prospects*. Dubuque, IO: Kendall/Hunt Publishing Company.
- Jones, Huw. 1994. *Population geography*. New York: Guildford Publications, Inc.
- Daugherty, Helen Ginn and Kenneth C.W. Kammeyer. 1995. *An introduction to population*. 2nd ed. New York: Guilford Press.
- Slater, Frances (ed.) 1986. *People and environments*. London: Collins Educational.
- Slater, Frances (ed.) 1991. *Societies, choices and environments: Issues and inquiries*. London: Collins Educational.
- Cutter, Susan L., Hilary Lambert Renwick, and William H. Renwick. 1985. *Exploitation, Conservation, Preservation: A Geographic Perspective on Natural Resource Use*. Totowa, NJ.: Rowman & Allenheld Pub.

The following sources may useful as additional reading material for the students or for the instructor:

- Ashford, L.S. and Z.A. Nobel. 1996. Population policy: Consensus and challenges. *Consequences* 2,2: 24,36.
- Brookfield, Harold. 1995. The 'population-environment nexus' and PLEC. *Global Environmental Change* 5,4 (September): 381+.
- Jiggins, Janice. 1994. *Changing the boundaries: Women-centered perspectives on population and the environment*. Island Press.
- Mazur, Laurie. 1994. *Beyond the numbers: A reader on population, consumption, and the environment*. Island Press.
- Uitto, Juha. 1995. Population, land management and environmental change: The genesis of PLEC within the United Nations University programme. *Global Environmental Change* 5,4 (September): 267-272.

Appendix C: Data Sources for this Module and Beyond

Crabbe, David and McBride, Richard. 1978. *The world energy book: An A-Z, atlas, and statistical source book.* Cambridge, Mass.: MIT Press. (A good, if dated energy reference book, with definitions of hundreds of terms and energy conversion factors)

International Energy Agency. (Year). *Energy statistics and balances of non-OECD countries.* Paris: OECD/IEA.

International Energy Agency. (Year). *Energy balances of OECD countries.* Paris: OECD/IEA.

Population Reference Bureau. 1990. *World environmental data sheet.* Washington, DC: Population Reference Bureau, Inc.

Population Reference Bureau. 1995. *World population: Fundamentals of growth.* Washington, DC: Population Reference Bureau, Inc.

Rand McNally. 1995. *World facts and maps.* Chicago, IL: Rand McNally and Co.

UNFPA. 1991. *Population, resources and the environment: The critical challenges.* New York: United Nations Population Fund. (Researched and drafted by Norman Myers).

United Nations Environment Programme (UNEP). *Environmental data report.* London: GEMS Monitoring and Assessment Research Center. (Choose most recent edition available at your institution)

U.S. Energy Information Administration. Annual. *Annual energy review.* DOE/EIA-0384. Washington DC: US Department of Energy.

U.S. Energy Information Administration. Annual. *International energy annual.* DOE/EIA-0219. Washington DC: US Department of Energy.

The World Bank. 1992. *World development report 1992: Development and the environment.* Oxford: Oxford University Press.

World Resources Institute. 1995. *World resources 1994-1995.* Washington, DC: World Resources Institute.

Appendix D: Videos and Computer Support

Videos

- "Madagascar"

  This movie illustrates the relationships of population pressure on resources and the environment. It was produced by the National Geographic Society and is available for purchase from them.

- "The population bomb"

  This movie was produced by CNN in 1992.

- "World population"

  A graphic simulation of the history of human population growth. Available from Zero Population Growth and Southern Illinois University of Carbondal (US$ 35). The simulation is only 6 minutes long, but can be shown several times to students.

  Zero Population Growth
  1400 Sixteenth Street
  Suite 320
  Washington, D.C. 20077-6640

In addition, all movies can be obtained through interlibrary loan for the class session in which you plan to show the movie. Allow sufficient time to acquire a copy of the movie.

Computer Support

- *PC Globe*

  This computer software provides instant profiles (geography, economy, demography, etc.) of 177 countries. It is available for approximately US$ 50 from the following address:

  Cromwell Systems Inc.
  2100 S. Rural Road
  Tempe, AZ 85282
  tel: 602-894-6866

- Internet Sources: See *Appendix E*.

Appendix E: Selected Internet/WWW Sites

If your institution has the resources and facilities to access the Internet, let students explore various sites on the World Wide Web. The sites listed below are just a small selection of a much larger set of options of national and international population centers. A quick Internet search with the "population" or "energy" keywords will reveal the information surplus currently accessible.

Population

http://www.psc.lsa.umich.edu Population Studies Center, University of Michigan
Provides access to various population resources, such as other population centers on the web, the US Census Bureau, the National Institute of Health, the ANU Demography and Population Studies WWW Virtual Library, and a population index for 1993 and 1994, etc. It also lists publications, data, research projects etc. of the Population Studies Center itself.

http://www.pop.psu.edu Population Research Institute (PRI), Penn State
This site gives general information about PRI, its mission, resources, and research programs, training opportunities, and projects. The population and demography information includes access to other population studies centers, US and international demographic data sources, and interesting connections to studies in related fields (anthropology, economics, geography, health, sociology, etc.).

http://elaine.ssc.wisc.edu/cdel/ Center for Demography and Ecology, U. of Wisconsin
CDE is a multi-disciplinary research cooperative for social scientific demographic research, mostly focussed on the US. Provides access to its own working papers, data library, and other local University of Wisconsin (Madison) resources, and to other population studies centers on the web.

http://www.popcouncil.org/ Population Council, New York
The Population Council is a nonprofit, nongovernmental, multinational, globally-networked research organization with headquarters in New York. Besides the typical access options (see other sites above), it provides (hourly updated!!!) world population numbers, news releases, publications, and job opportunities and internships.

gopher//gopher.undp.org:70/1/ungophers/popin UN Population Information Network
The United Nations Population Information Network (POPIN) lists conferences, congresses and symposia related to population issues, contains the documentation for the UN Commission on Population & Development, the international Conference on Population and Development (ICPD), general POPIN information, regional POPIN networks, the UN population Fund (UNFPA), and data on world demographic trends, published by the UN population Division.

http://biomed.nus.mstat/welcome.html **MEDISTAT, Nat. University of Singapore**

MEDISTAT is an on-line information system for health and population statistics. It began in 1988 as a private local information service, turned soon into a free community service project, and has become a World Wide Web site in 1988.

Energy

http://www.osti.gov/ **US Department of Energy**

The Government's Office of Scientific and Technical Information maintains a web site that includes among other things an "Energy Awareness Homepage." One can learn here more about the Department of Energy, and get a quick overview of upcoming events, conferences, press releases and other hot topics, educational, training, and job opportunities.

http://www.doe.gov **USDOE, OpenNet**

The DOE's OpenNet is said to be "a major step in fulfilling Secretary O'Leary's . . . commitment to openness with regard to declassified documents."

http://appollo.sti.gov/home.html **US DOE, homepage**

DOE's news and hot topics include press releases, news briefs, information about the sustainable energy initiative, access to DOE's Lessons Learned homepage, reports from special task forces and committees, budget highlights, and congressional questions and answers, and testimony database.

http://www.er.doe.gov/ **USDOE, Office of Energy Research**

Programs at this DOE Office fund basic research on energy-related topics. Through this page, one has access to a description of its basic energy science, technology research, fusion energy research, health and environmental research programs.

http://www.esd.ornl.gov/doe-labs/doe-labs.html **USDOE, Oak Ridge Nat'l Lab**

http://agency.resource.cagov/cechomepage.html **California Energy Commission**

Contains the CA Energy Commission's mission statement, access to energy policy reports, job announcement, energy-related legislation, services and funding programs, a directory of California's energy companies (a kind of "yellow Pages"), other CA-relevant information, and links to other energy sites on the web.

http://www.llnl.gov **Lawrence Livermore National Laboratory**

This DOE laboratory is located at the University of California; this web site describes its work, projects, history, provides access to all kinds of energy-related resources, and the Lab's publications.

http://www.ciesin.org/kiosk/crestkiosk.html **CIESIN Kiosk**

The Center for International Earth Science Information has an electronic bookshelf with reports and papers from the Center for Renewable Energy and Sustainable Technology.

http://www-esl.tamu.edu/ **Energy Systems Laboratory**

The Energy Systems Laboratory is a research focus for studies on alternative energy and energy conservation within the Texas Engineering Experiment Station at Texas A&M University. It offers access to its publications, data, available software, and its LoanSTAR Program (see below).

http://loanstar.tamu.edu/loanstar/about_LoanSTAR.html **MECR**

The Monthly Energy Consumption Report (MECR) can be accessed at this Texas A&M University cite. STAR stands for "Save Taxes And Resources."

http://www.ugcs.caltech.edu/~stacy/geo.html **US Nat'l Trade Data Bank**

This Web site cites world energy consumption data.

Appendix F: References on Closely Related Subject Matters

The following is a list of newspaper articles that provide some real world context to the themes dealt with in this module. Mostly they deal with food supply, conflict, migration, and population growth. More than anything, these references point to an easily accessible information source that you might ask your students to follow throughout the course of the semester: the news media.

Dillin, John. 1994. Going forth, the nations multiply unevenly. *The Christian Science Monitor*

Hanley, Charles J. 1994. Kenya a small bright spot in fight to curb population. *Rocky Mountain News* September 5: 50A (for accompanying graphic: 51A).

Kongshaug, Nils. 1995. A thousand secret paths lead from Albania. *The Christian Science Monitor* March 20: 7.

Matloff, Judith. 1995. Poor nations confront choice of trees or jobs. *The Christian Science Monitor* August 16: 1, 8

Press, Robert M. 1990. Going beyond food relief. *The Christian Science Monitor* August 29: 4.

Press, Robert M. 1995. Nomads and farmers in Kenya war over increasingly scarce land. *The Christian Science Monitor* January 18: 6.

Sly, Liz. 1995. Circle of poverty. *The Chicago Tribune*.

Associated Press. 1995. Number of refugees grows to all-time high. *Rocky Mountain News* June 11: 44A.

Appendix G: Suggested Readings

The AAG was able to obtain reprint permission from the original publishers for only some of the readings suggested in the activities of this module. To avoid copyright problems, we suggest you make these readings available to your students by putting them on reserve. The following readings are enclosed:

World Bank. 1992. Development and the environment: A false dichotomy. World Development Report 1992: Development and Environment. Oxford: Oxford University Press, pp. 25-43. (Reprinted with the permission of the World Bank.)

1

Development and the environment: a false dichotomy

Economic development and sound environmental management are complementary aspects of the same agenda. Without adequate environmental protection, development will be undermined; without development, environmental protection will fail.

More than 1 billion people today live in abject poverty. The next generation will see the world's population rise by 3.7 billion, even if progress in reducing population growth accelerates. Most of these people will be born into poor families. Alleviating poverty is both morally imperative and essential for environmental sustainability.

Economic growth is essential for sustained poverty reduction. But growth has often caused serious environmental damage. Fortunately, such adverse effects can be sharply reduced, and with effective policies and institutions, income growth will provide the resources for improved environmental management.

The environmental mistakes of the past do not have to be repeated. Today, countries have more choices. They can choose policies and investments that encourage more efficient use of resources, substitution away from scarce resources, and the adoption of technologies and practices that do less environmental harm. Such changes will ensure that the improvements in human welfare which development brings are lasting.

More people today live longer, healthier, and more productive lives than at any time in history. But the gains have been inadequate and uneven. More than 1 billion people still live in abject poverty. To reduce poverty, sustained and equitable economic growth is essential. But past economic growth has often been associated with severe degradation of the natural world. On the surface, there appears to be a tradeoff between meeting people's needs—the central goal of development—and protecting the environment. This Report will argue that in every realm of economic activity, development can become more sustainable. The key is not to produce less, but to produce differently. This chapter explores the relationship between economic activity and the environment, emphasizing the concerns of developing countries.

The context: population, poverty, and economic growth

Population growth

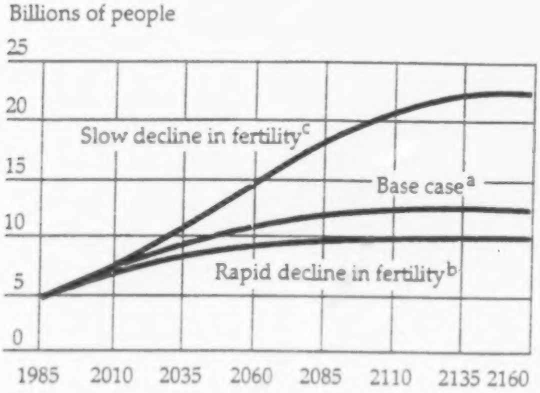
The second half of the twentieth century has been a demographic watershed. By midcentury the rate of population growth in developing countries had risen to unprecedented levels as mortality declined and life expectancy increased. These gains were the result of progress in living standards, sanitary conditions, and public health practices, particularly the introduction of antibiotics, the increased use of vaccinations, and antimalarial spraying. World population growth peaked at 2.1 percent a year in 1965–70, the most rapid rate of increase in history. Population growth has now slowed to 1.7 percent as more countries have begun a transition toward lower fertility. Even so, world population now stands at 5.3 billion and is increasing by 93 million a year.

To project future trends in fertility—the largest factor in determining population growth—judgments have to be made about two key questions: when will a country begin its demographic transition, and how fast will fertility decline once the transition begins? Figure 1.1 illustrates three alternative paths for world population. Under the World Bank's base case projections, world population growth would decline slowly, from 1.7 percent a year in 1990 to about 1 percent a year by 2030. World population would more than double from current levels and would stabilize at about

The World Bank. 1992. World Development Report. Oxford: Oxford University Press.

World population will at least double and may quadruple

Figure 1.1 World population projections under different fertility trends, 1985-2160



a. Countries with high and nondeclining fertility levels begin the transition toward lower fertility by the year 2005 and undergo a substantial decline - by more than half in many cases - over the next forty years. All countries reach replacement fertility levels by 2060.
b. Countries not yet in transition toward lower fertility begin the transition immediately. For countries already in transition, total fertility declines at twice the rate for the base case.
c. Transition toward lower fertility (triggered when life expectancy reaches 53 years) begins after 2020 in most low-income countries. For countries in transition, declines are half the rate for the base case.
Source: World Bank data.

12.5 billion around the middle of the twenty-second century. Two-thirds of the increase would occur by 2050, and 95 percent of population growth would take place in developing countries.

Alternative paths are possible. The scenario of rapid fertility decline illustrated in Figure 1.1 is comparable to the historical experience of, for example, Costa Rica, Hong Kong, Jamaica, Mexico, and Thailand. The scenario of slow fertility decline is consistent with the experience of such countries as Paraguay, Sri Lanka, Suriname, and Turkey. The stable population of 10.1 billion in the rapid fertility decline scenario is about 2.4 billion less than that in the base case, but it is still almost double the present size. In stark contrast, with a slow decline of fertility, population increases more than fourfold, to about 23 billion, and stabilizes only toward the end of the twenty-second century. Few demographers expect world population to reach 23 billion, but the projection shows what might happen if fertility transitions are delayed in many countries.

This tremendous range of possible long-term population trends depends largely on what happens in Africa and in the Middle East. Together, these regions account for 85 to 90 percent of the differences between the alternative scenarios and the base case. Sub-Saharan Africa alone contributes more than two-thirds of the difference under the slow fertility decline scenario. Total fertility rates (measured as births per woman) in Sub-Saharan Africa as a whole have remained unchanged at about 6.5 for the past twenty-five years—a level much higher than in other parts of the world that have similar levels of income, life expectancy, and female education.

Recent statistics provide encouraging indications that a number of African countries are at or near a critical turning point. Total fertility rates have already fallen in Botswana (6.9 in 1965 to 4.7 in 1990), Zimbabwe (8.0 in 1965 to 4.9 in 1990), and Kenya (8.0 in 1965 to 6.5 in 1990) and are beginning to decline in Ghana, Sudan, and Togo. The base case projections, which assume that these positive trends will continue, imply that Sub-Saharan Africa's population will rise from 500 million at present to about 1.5 billion by 2030 and almost 3 billion by 2100. Apart from its terrible effects on health and welfare, the AIDS virus could reduce African population growth rates by as much as 0.5-1.0 percentage points in the early decades of the next century. But because increased mortality from AIDS may delay fertility declines, the overall impact of the disease is ambiguous.

POPULATION GROWTH AND THE ENVIRONMENT. Population growth increases the demand for goods and services, and, if practices remain unchanged, implies increased environmental damage. Population growth also increases the need for employment and livelihoods, which—especially in crowded rural areas—exerts additional direct pressure on natural resources. More people also produce more wastes, threatening local health conditions and implying additional stress on the earth's assimilative capacity.

Countries with higher population growth rates have experienced faster conversion of land to agricultural uses, putting additional pressures on land and natural habitat. An econometric study of twenty-three Latin American countries found that expansion of agricultural area continues to be positively related to population growth, after controlling for such factors as agricultural trade, yield in-

Box 1.1 The population-agriculture-environment nexus in Sub-Saharan Africa

Rapid population growth, agricultural stagnation, and environmental degradation have been common to most Sub-Saharan countries in recent decades. These three factors have been mutually reinforcing. The World Bank recently completed a study of this "nexus" with the purpose of better understanding causal links and identifying remedies. Its preliminary findings are summarized here.

The equilibrium upset

Shifting cultivation and grazing have been appropriate traditional responses to abundant land, scarce capital, and limited technology. As population densities grew slowly in the first half of this century, these extensive systems evolved into more intensive systems, as in Rwanda, Burundi, the Kenyan highlands, and the Kivu Plateau in Zaire. This slowly evolving system has, however, proved unable to adapt to sharply accelerated population growth over the past four decades. Traditional uses of land and fuel have depleted soil and forests and contributed to agricultural stagnation. Stagnant incomes and the absence of improvements in human welfare have impeded the demographic transition. A combination of high population densities and low investment has caused arable land per person to decline from 0.5 hectare in 1965 to 0.3 hectare in 1987. As a result, in many parts of Burundi, Kenya, Lesotho, Liberia, Mauritania, and Rwanda fallow periods are no longer sufficient to restore fertility.

Population growth drives some people to cultivate land not previously used for farming—in semiarid areas and in tropical forests where soil and climatic conditions are poorly suited for annual cropping or for the practices employed by the new migrants. These problems are most severe in parts of the Sahel, in parts of mountainous East Africa, and in the dry belt stretching from Namibia through Botswana, Lesotho, and southern Mozambique. There is strong evidence that economic stagnation is delaying declines in fertility; family size may be higher (to provide additional labor) where land damage is greatest and fuelwood supplies are depleted. An integrated approach to the problem is needed.

Toward solutions

The traditional development approach, which emphasized supplying services and technologies, must be complemented by a strategy of promoting demand—for appropriate agricultural practices and inputs, for fewer children, and for resource conservation. Demand for these things can be promoted by:

- Removing subsidies that distort prices and incentives—to promote more efficient use of resources
- Improving land use planning—to promote intensification and protect valuable natural ecosystems
- Clarifying resource ownership and land tenure, giving legal recognition to traditional common-property management and private ownership, and reducing state ownership—to encourage investment
- Expanding educational programs for girls and employment opportunities for women and improving information on health and nutrition, in all cases through the use of community groups, NGOs, and the private sector—to promote demand for smaller families
- Expanding investment in and maintenance of rural infrastructure, especially roads, water supply, and sanitation—to improve production incentives, productivity, and health.

creases, and availability of land. A study of six Sub-Saharan African countries indicates that technological innovations are not keeping up with the demands of rapidly rising rural populations. As a consequence, in many places—Ethiopia, southern Malawi, eastern Nigeria, and Sierra Leone—farming is being intensified through shorter fallow periods rather than through the use of better inputs or techniques. Rapid population growth in these areas has led to the mining of soil resources and to stagnating or declining yields. In some circumstances, especially in rural Africa, population growth has been so rapid that traditional land management has been unable to adapt to prevent degradation. The result is overgrazing, deforestation, depletion of water resources, and loss of natural habitat (Box 1.1).

The distribution of people between countryside and towns also has important implications for the types of stress placed on the environment. In 1990 most people lived in rural areas. By 2030 the opposite will be true: urban populations will be twice the size of rural populations. Developing country cities as a group will grow by 160 percent over this period, whereas rural populations will grow by only 10 percent. By 2000 there will be twenty-one cities in the world with more than 10 million inhabitants, and seventeen of them will be in developing countries.

The pattern will vary substantially among regions. Over the next thirty years urban population growth will average 1.6 percent a year in Latin America, 4.6 percent in Sub-Saharan Africa, and 3 percent in Asia. Rural populations are expected to

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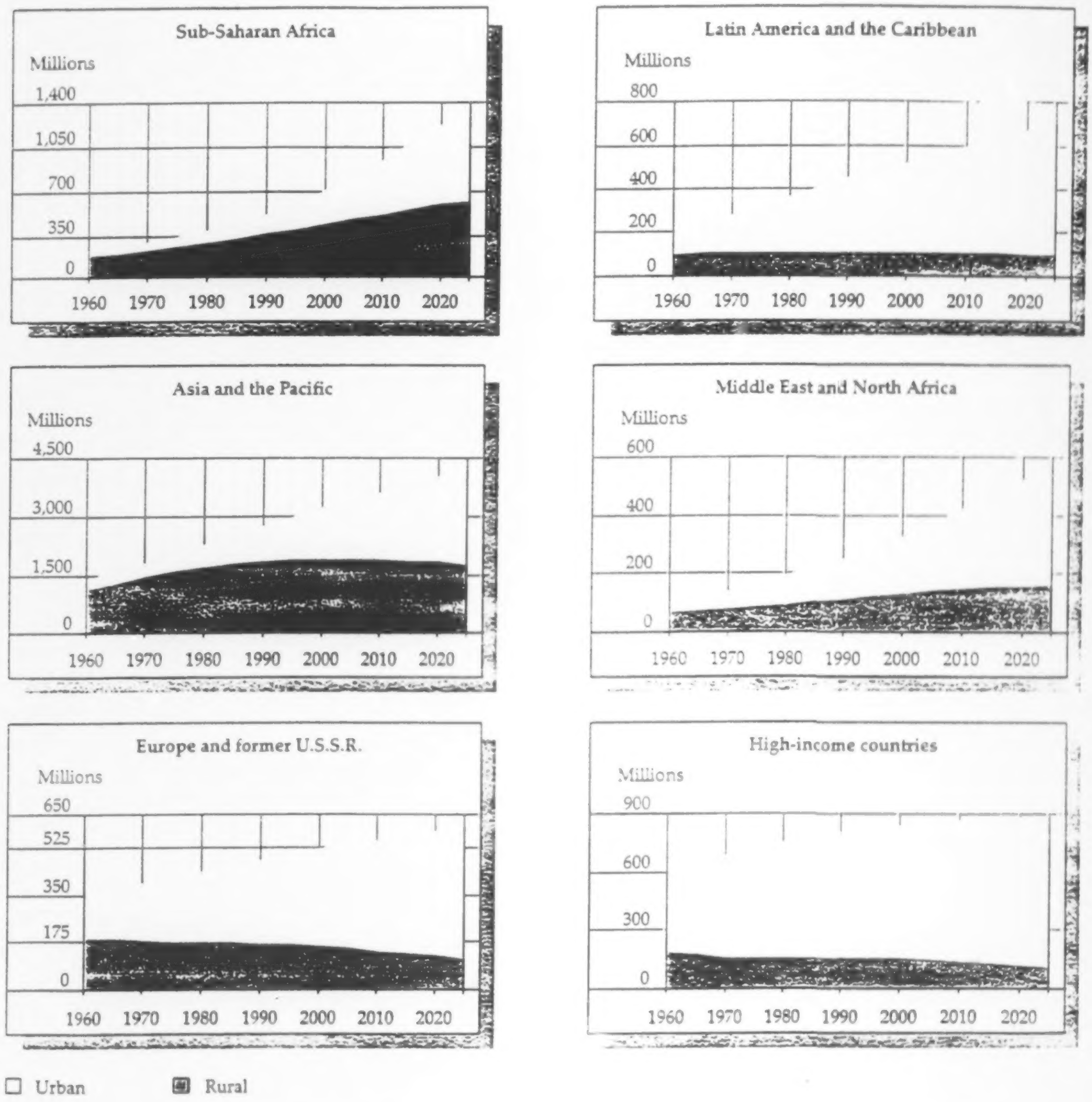
Urban populations will overtake rural populations for the first time in history

Figure 1.2 Rural and urban population in developing regions and high-income countries, 1960-2025



Note: Data after 1985 are projections.
Sources: World Bank data; United Nations 1990.

decline in absolute terms within a generation in all regions except Sub-Saharan Africa, the Middle East and North Africa, and Central America (Figure 1.2). Asia's rural population will continue to increase until the turn of the century but is expected to fall back to current levels by about 2015. In high-income countries and in Eastern Europe and the former U.S.S.R. the numbers living in rural areas have been declining steadily, and in most South American countries, too, urbanization has brought about some decline in rural populations.

The pace of urbanization poses huge environmental challenges for the cities. That is why much of this Report is devoted to the problems of sanitation, clean water, and pollution from industry, energy, and transport. But urbanization will also affect the nature of rural environmental challenges. Successful urbanization and the associated income growth should ease the pressures caused by encroachment on natural habitats—largely driven by the need for income and employment—but will increase the pressures stemming from market demand for food, water, and timber. In much of Sub-Saharan Africa, the Middle East and North Africa, and Central America rural populations are likely to increase by about 50 percent over the next generation, and direct pressure on natural resources, particularly by poor subsistence farmers, will intensify.

POLICIES FOR REDUCING POPULATION GROWTH. The declining fertility rates associated with the base case projections should not be taken for granted. They are rapid by historical standards and will require solid progress on four fronts: incomes of poor households must rise, child mortality must decline, educational and employment opportunities (especially for women) must expand, and access to family planning services must be increased.

Investments in female education have some of the highest returns for development and for the environment. Evidence from a cross-section of countries shows that where no women are enrolled in secondary education, the average woman has seven children, but where 40 percent of all women have had a secondary education, the average drops to three children, even after controlling for factors such as income. Better-educated mothers also raise healthier families, have fewer and better-educated children, and are more productive at home and at work. Investments in schools, teachers, and materials are essential. But so too are policies to encourage enrollment, such as scholarship programs. In Bangladesh a scholarship program has succeeded in almost doubling female secondary enrollment, as well as promoting higher labor force participation, later marriage, and lower fertility rates.

Efforts to expand family planning programs have contributed to significant progress; the rate of contraceptive use in developing countries rose from 40 percent in 1980 to 49 percent in 1990. But for the base case projections to be realized, the rate would need to increase by another 7 percentage points by 2000 and by yet another 5 percentage points by 2010. Unmet demand for contraceptives is large—it ranges from about 15 percent of couples in Brazil, Colombia, Indonesia, and Sri Lanka to more than 35 percent in Bolivia, Ghana, Kenya, and Togo. Meeting this demand is essential for reaching even the base case projections and will require that total annual expenditure on family planning increase from about $5 billion to about $8 billion (in 1990 prices) by 2000. An additional $3 billion would be required to achieve the rapid fertility decline scenario. Choices about family planning and education policies today will determine world population levels, and the consequent pressures on the environment, in the next century.

The persistence of poverty

The primary task of development is to eliminate poverty. Substantial progress has been achieved over the past twenty-five years. Average consumption per capita in developing countries has increased by 70 percent in real terms; average life expectancy has risen from 51 to 63 years; and primary school enrollment rates have reached 89 percent. If these gains were evenly spread, much of the world's poverty would be eliminated. Instead, more than one-fifth of humanity still lives in acute poverty.

New estimates prepared for this Report reveal a negligible reduction in the incidence of poverty in developing countries during the second half of the 1980s (Table 1.1). The numbers of poor have increased at almost the rate of population growth over the period—from slightly more than 1 billion in 1985 to more than 1.1 billion by 1990.

Asia, with its rapid income growth, continues to be the most successful at alleviating poverty. China was an exception in the second half of the 1980s; although its incidence of poverty remains, for its income, very low, the new estimates reflect some adverse changes for the poorest in that country as a result of a more uneven distribution of income. In most other East Asian countries poverty continued to decline. South Asia, including India, has maintained a steady but undramatic decline in poverty. The experience in other developing regions has been markedly different from that in Asia. All poverty measures worsened in Sub-Saharan Africa, the Middle East and North Africa, and Latin America and the Caribbean.

What are the prospects for poverty alleviation to the end of this century? The estimates presented in Table 1.1 are based on the projections of income

Table 1.1 Poverty in the developing world, 1985–2000

Region	*Percentage of population below the poverty line* 1985	1990	2000	*Number of poor (millions)* 1985	1990	2000
All developing countries	30.5	29.7	24.1	1,051	1,133	1,107
South Asia	51.8	49.0	36.9	532	562	511
East Asia	13.2	11.3	4.2	182	169	73
Sub-Saharan Africa	47.6	47.8	49.7	184	216	304
Middle East and North Africa	30.6	33.1	30.6	60	73	89
Eastern Europe[a]	7.1	7.1	5.8	5	5	4
Latin America and the Caribbean	22.4	25.5	24.9	87	108	126

Note: The poverty line used here—$370 annual income per capita in 1985 purchasing power parity dollars—is based on estimates of poverty lines from a number of countries with low average incomes. In 1990 prices, the poverty line would be approximately $420 annual income per capita. The estimates for 1985 have been updated from those in *World Development Report 1990* to incorporate new data and to ensure comparability across years.

a. Does not include the former U.S.S.R.

Source: Ravallion, Datt, and Chen 1992.

growth presented below (see Table 1.2) and assume that the distribution of income within countries remains constant. Under these assumptions, the number of poor in Asia would continue to decline, and the adverse poverty trends in Latin America and Eastern Europe would be reversed with economic recovery in those regions. Sub-Saharan Africa is the only region in which the situation is expected to deteriorate; with increases in the proportion of the population in poverty, the number of poor would rise by about 9 million a year, on average. By the end of the decade about one-half of the world's poor will live in Asia and one-quarter will live in Sub-Saharan Africa.

It is sobering to compare these estimates with those in *World Development Report 1990*. That report identified a path of poverty reduction that would reduce the absolute number of poor in the world by 300 million between 1985 and 2000. The path was presented to illustrate what could be accomplished with sound policies in both developing and industrial countries. Sadly, that target appears no longer feasible, partly as a result of the severity of the current recession and the disappointing progress in the 1985–90 period. Even under fairly hopeful assumptions about economic recovery in the rest of the decade, the absolute number of poor in the world at the turn of the century will probably be higher than in 1985.

POVERTY AND THE ENVIRONMENT Alleviating poverty is both a moral imperative and a prerequisite for environmental sustainability. The poor are both victims and agents of environmental damage. About half of the world's poor live in rural areas that are environmentally fragile, and they rely on natural resources over which they have little legal control. Land-hungry farmers resort to cultivating unsuitable areas—steeply sloped, erosion-prone hillsides; semiarid land where soil degradation is rapid; and tropical forests where crop yields on cleared fields frequently drop sharply after just a few years. Poor people in crowded squatter settlements frequently endure inadequate access to safe water and sanitation, as well as flooding and landslides, industrial accidents and emissions, and transport-related air pollution. The poor are often exposed to the greatest environmental health risks, and they tend to be the most vulnerable to those risks because of their poverty. The impact of environmental degradation on the poor will be described in Chapter 2.

Poor families often lack the resources to avoid degrading their environment. The very poor, struggling at the edge of subsistence, are preoccupied with day-to-day survival. It is not that the poor have inherently short horizons; poor communities often have a strong ethic of stewardship in managing their traditional lands. But their fragile and limited resources, their often poorly defined property rights, and their limited access to credit and insurance markets prevent them from investing as much as they should in environmental protection (Box 1.2). When they do make investments, they need quick results. Studies in India, for example, found implicit discount rates among poor farmers of 30–40 percent, meaning that they were willing to make an investment only if it would treble its value in three years. Similarly, efforts to introduce soil conservation and water-harvesting techniques in Burkina Faso showed that the practices most likely to be adopted were those that could deliver an increase in yields within two or three years. In many countries ef-

Box 1.2 Droughts, poverty, and the environment

Agriculture is a risky business everywhere, but perhaps the most debilitating risk is that of drought in semiarid tropical areas. Households in the poor rural societies that inhabit many of these regions have little to fall back on. The combination of poverty and drought can also have serious environmental consequences that threaten future agricultural productivity and the conservation of natural resources. For example, poor people are induced to scavenge more intensively during droughts, seeking out wood and other organic fuels, wildlife, and edible plants, both to eat and to sell. But because the plants, trees, and wildlife are already under stress from drought, such scavenging aggravates deforestation and damage to watersheds and soil. Livestock farmers tend to concentrate their animals near water holes during droughts, and the consequent overgrazing may cause long-term damage to the soil.

Many farming practices in semiarid areas have the potential to worsen the harm that droughts cause to natural resources. For example, arable cropping, by increasing soil exposure, makes the soil more vulnerable to wind and rain erosion and to loss of moisture and nutrients. These effects can be pronounced even in normal years but are particularly severe in droughts. Since farmers cannot predict droughts, they typically clear and plant the land in preparation for a normal season. When the crops subsequently fail, the land is left exposed to the full rigors of sun, wind, and rain.

The ways in which farmers try to reduce risk, although perfectly rational from their own point of view, can sometimes impose environmental costs on local communities. For example, a household may farm more than one separate parcel of land in order to exploit local variations in conditions and thus reduce production risks. But because farmers have smaller land parcels at any one location, the environmental costs (such as soil erosion and water runoff) associated with their farming practices are less likely to be felt on their own farms and more likely to be borne by their neighbors. Individual farmers have little incentive to address the problem. Even when they do, a solution may be difficult because it can require organizing neighboring farmers to undertake a joint investment (such as contouring or terracing).

A similar problem can arise in common-property pastoral farming if farmers carry extra cattle as insurance against drought. Because farmers are likely to defer as long as possible selling their cattle, this simple form of insurance often leads to overgrazing in drought years, increasing the likelihood of permanent damage to the pasture.

Markets are also inadequate for spreading risks in drought-prone regions because so many people are affected at once. Although credit markets can sustain consumption over the course of normal variations in family incomes, they may not be able to provide the huge amounts of credit required in drought years, when large numbers of people need to borrow at the same time. Governments must therefore provide relief employment and targeted food assistance in drought years, and effective drought insurance schemes may be needed.

forts to encourage rural communities to plant woodlots have failed when people had to wait until the trees reached maturity to realize a return but have succeeded when products such as building poles and fodder could be harvested more quickly.

In many parts of the world women play a central part in resource management and yet enjoy much less access to education, credit, extension services, and technology than do men. In Sub-Saharan Africa women provide an estimated 50–80 percent of all agricultural and agroprocessing labor. Despite such high levels of economic activity, women in many countries have no or only limited rights of tenure to land and cultivated trees. This constrains their access to credit for investments in new technologies. Women are also frequently neglected by agricultural and forestry extension services. When women have been given equal opportunities (as in combating soil erosion in Cameroon), they have shown effective leadership in managing natural resources.

Substantial synergies exist between alleviating poverty and protecting the environment. Since the poor are less able than the rich to "buy out of" environmental problems, they will often benefit the most from environmental improvements. In addition, the economic activities stimulated by environmental policies—such as the use of agroforestry and windbreaks to slow soil erosion and the construction of infrastructure for water supply and sanitation—are often labor-intensive and thus can provide employment. Targeted social safety nets make it less necessary for the poor to "mine" natural resources in times of crisis. Extension and credit programs and the allocation of land rights to squatters increase the ability of the poor to make environmental investments and manage risks. Investments in water and sanitation and in pollution

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abatement will also benefit the poor by improving their health and productivity. But it is equitable economic growth, coupled with education and health services, that is most urgently needed. This will enable the poor to make environmental investments that are in their own long-term interest. It will also be essential for accelerating the demographic transition; better-off and better-educated couples have fewer children.

Economic growth—long-term trends and prospects

Average per capita incomes in developing countries rose 2.7 percent a year between 1950 and 1990—the highest sustained rate of increase in history. But the pace of economic growth has differed greatly among regions. Asian countries, which account for 65 percent of the population of the developing world, grew at an average rate of 5.2 percent a year in the 1970s and 7.3 percent in the 1980s, while growth in the non-Asian developing countries decelerated from 5.6 percent in the 1970s to 2.8 percent in the 1980s. Asia was the only developing region to achieve sustained per capita income growth during the 1980s.

RECENT ECONOMIC DEVELOPMENTS. The 1990s started badly for developing countries. In both 1990 and 1991 per capita income in developing countries as a whole fell, after rising every year since 1965. The setback was caused largely by extraordinary events—the war in the Middle East, and economic contraction in Eastern Europe and in the former U.S.S.R. Recession in several high-income countries also contributed to the stagnation of export growth in developing countries. The projections presented in Table 1.2 assume that industrial countries will grow more slowly in the 1990s than in the 1980s. This context provides all the more reason to accelerate policy reform in developing countries. Experience has shown that, on average, the effect of domestic policies on long-run growth is about twice as large as the effects attributable to changes in external conditions.

With continued progress on economic reform in developing countries, GDP growth is projected to increase to about 5 percent a year for the decade as a whole—significantly higher than the 3.4 percent achieved in the 1980s. Growth in Asia is expected to slow from the high levels of the 1980s but will remain well above the average for developing countries. Latin America, Eastern Europe, and the Middle East and North Africa are all expected to grow more rapidly during the remainder of the 1990s. Sub-Saharan Africa's growth performance will improve in comparison with the 1980s, but the gains will be small.

LONGER-TERM PROSPECTS. Because many environmental issues evolve slowly, this Report takes a longer view than usual, giving special attention to the next four decades. About 3.7 billion people will be added to the world's population during this period—many more than in any previous generation, and probably more than in any succeeding one. Economic projections over this length of time are, of course, subject to great uncertainty. They are presented in Figure 1.3 not as predictions but as indicators of what historical experience suggests is likely to occur.

World GDP could rise from about $20 trillion in 1990 to $69 trillion in 2030 in real terms. For the

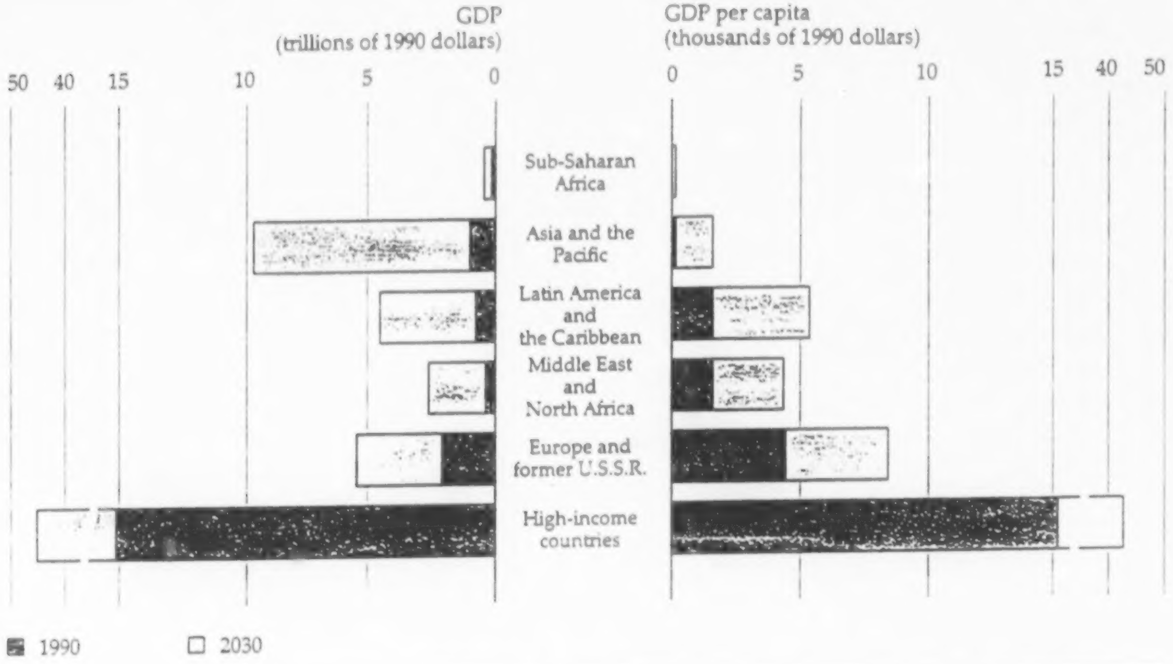
Table 1.2 Growth of real per capita income in industrial and developing countries, 1960–2000
(average annual percentage change)

Country group	*1960–70*	*1970–80*	*1980–90*	*1990*	*1991*[a]	*1990–2000*[a]
High-income countries	4.1	2.4	2.4	2.1	0.7	2.1
Developing countries	3.3	3.0	1.2	−0.2	−0.2	2.9
Sub-Saharan Africa	0.6	0.9	−0.9	−2.0	−1.0	0.3
Asia and the Pacific	2.5	3.1	5.1	3.9	4.2	4.8
East Asia	3.6	4.6	6.3	4.6	5.6	5.7
South Asia	1.4	1.1	3.1	2.6	1.5	3.1
Middle East and North Africa	6.0	3.1	−2.5	−1.9	−4.6	1.6
Latin America and the Caribbean	2.5	3.1	−0.5	−2.4	0.6	2.2
Europe	4.9	4.4	1.2	−3.8	−8.6	1.9
Eastern Europe	5.2	5.4	0.9	−8.3	−14.2	1.6
Memorandum:						
Developing countries weighted by population	3.9	3.7	2.2	1.7	2.2	3.6

Note: Totals do not include the former U.S.S.R.
a. Estimates.
Source: World Bank 1992.

Average per capita incomes in developing countries will triple by 2030

Figure 1.3 GDP and GDP per capita in developing regions and high-income countries, 1990 and 2030



Note: Data for 2030 are projections.
Source: World Bank data.

developing countries as a whole, average incomes could more than triple in real terms, from an average of $750 today (the level of Côte d'Ivoire) to about $2,500 in 2030, roughly the income per capita of Mexico today. Substantial regional differences would persist, although in the aggregate the gap between income levels in developing and industrial countries would narrow. By the middle of the next century developing countries' share of world income would have risen from less than one-quarter to almost one-half, and if trends continued, it would rise to more than three-quarters by 2100. The most rapid growth rates are expected in Asia, particularly in East Asia, where per capita incomes would be more than $3,300 in 2030. Although growth rates in South Asia will be robust, the tripling of average incomes during the next generation would still leave them at only about $1,000 per capita. Average per capita incomes in Latin America and in the Middle East and North Africa could exceed $5,000 and $4,000, respectively—well above the average for developing countries. Economic recovery in Eastern Europe would raise average per capita incomes to more than $9,000 by 2030, while those in the former U.S.S.R. could rise to more than $8,000. Projections for Sub-Saharan Africa are the most sobering; under present productivity trends and population projections trends in total output would rise fourfold, but per capita incomes would still reach only $400.

Sustaining development

In terms of incomes and output, the world will be a much richer place in the next century. But will the environment be much poorer? Will future generations be worse off as a result of environmental degradation that results from economic decisions made today? Will increases in the scale of eco-

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nomic activity be sustainable in the face of increasing pressure on natural resources? Prospective changes of the size described above raise fundamental questions about the kind of world we will bequeath to our children and about the nature and goals of development.

What is development?

Development is about improving the well-being of people. Raising living standards and improving education, health, and equality of opportunity are all essential components of economic development. Ensuring political and civil rights is a broader development goal. Economic growth is an essential means for enabling development, but in itself it is a highly imperfect proxy for progress.

The first step in improving social choices is to measure progress correctly. It has long been recognized that measures of, for example, educational opportunity, infant mortality, and nutritional status are essential complements to GDP or GNP. Some have even tried to merge these indices to capture progress in development. The human development index constructed by the United Nations Development Programme (UNDP) is such an effort.

The fact that environmental damage hurts people—both today and in the future—provides additional grounds for rethinking our measurement of progress. Indeed it raises special concerns, for unlike education, health, nutrition, and life expectancy, which tend to be improved by economic growth, the environment is sometimes damaged by that growth. Furthermore, the people suffering from the damage may be different from those enjoying the benefits of growth. They may, for example, be today's poor, or they may be future generations who inherit a degraded environment. For these reasons it is essential to assess the costs to human welfare of environmental damage—a central theme of this Report—and to take account of the distributional impacts of policies, particularly for the poor.

What is sustainable?

Sustainable development is development that lasts. A specific concern is that those who enjoy the fruits of economic development today may be making future generations worse off by excessively degrading the earth's resources and polluting the earth's environment. The general principle of sustainable development adopted by the World Commission on Environment and Development (*Our Common Future,* 1987)—that current generations should "meet their needs without compromising the ability of future generations to meet their own needs"—has become widely accepted and is strongly supported in this Report.

Turning the concept of sustainability into policy raises fundamental questions about how to assess the well-being of present and future generations. What should we leave to our children and grandchildren to maximize the chances that they will be no worse off than ourselves? The issue is the more complicated because our children do not just inherit our pollution and resource depletion but also enjoy the fruits of our labor in the form of education, skills, and knowledge (human capital), as well as physical capital. They may also benefit from investments in natural resources—improvement in soil fertility and reforestation, for example. Thus, in considering what we pass on to future generations, we must take account of the full range of physical, human, and natural capital that will determine their welfare and their bequests to their successors.

Intergenerational choices of this kind are reflected in the discount rate used to assess investments. The discount rate is the mechanism through which present and future costs and benefits are compared. The lower the discount rate, the more it is worth investing today to make future gains. It is sometimes claimed that a lower discount rate—even a zero discount rate—should be used in order to give appropriate weight to the long-term consequences of environmental change. This argument is erroneous. Provided that the environmental effects of projects are fully taken into account—which they often are not—it is always best to choose the investments which generate the highest net rate of return. Encouraging investments that yield a lower net rate of return is wasteful; it implies a loss of welfare and of income that might have been devoted to environmental objectives.

Weighing costs and benefits

Addressing environmental problems requires not that discount rates be artificially lowered but rather that the value of the environment be factored into decisionmaking. Values that are difficult to measure are often implicit in decisionmaking, but the tradeoffs are not well thought through. There is a clear need to make such costs and benefits as explicit as possible so as to better inform policymakers and citizens. This does not imply that it is possible, or even desirable, to put mone-

Box 1.3 Natural resource and environmental accounting

The limitations of conventional measures of economic activity, such as GNP and national income, as indicators of social welfare have been well known for decades. Recently, the perception has grown that these indicators, which are based on the United Nations System of National Accounts (SNA), do not accurately reflect environmental degradation and the consumption of natural resources. Several alternative approaches have been developed. Early work in this area was conducted by some OECD countries, notably Norway and France. Recent attempts to apply natural resource accounting to developing countries have been made by UNEP, the United Nations Statistical Office (UNSO), the World Bank, and the World Resources Institute. These methods differ in both comprehensiveness and objectives.

Broadly, there are two criticisms of the SNA framework. First, aggregates such as GNP may be inadequate measures of economic activity when environmental damage occurs. The depreciation of some forms of capital, such as machinery, is taken into account, but investments in human capital and depletion of environmental capital, including nonrenewable natural resources, are not measured.

Second, it is argued, by neglecting the services provided by natural resources, the SNA limits the information available to policymakers. Leaving out these services ignores the impact of economic activity on the environment in its role both as a "sink" for wastes and a "source" of inputs. It is argued that ignoring these services and their effects on economic activity makes the national income accounts misleading for formulating economic policies, particularly in economies that are heavily dependent on natural resources.

The various approaches to natural resource and environmental accounting have divergent aims. Each responds to a different problem with the SNA framework. The simplest approaches attempt to measure more accurately the responses to environmental degradation and protection that are already imperfectly measured in the national income accounts. Examples include work in Germany, the Netherlands, and the United States on estimating pollution abatement expenditures. A second approach responds to the inconsistent treatment of natural capital in the SNA and attempts to account explicitly for the depletion of natural resources; estimates of depletion are applied to conventionally measured income to derive a measure of net income. This approach has been applied in Indonesia for forests, petroleum, and soils, in Costa Rica for fisheries and forests, and in China for minerals. Finally, the physical accounting method used by Norway and the effort to integrate environmental and resource use with economic activity being developed by the UNSO both attempt to improve the information available for environmental management. The Norwegian system focuses primarily on the country's main natural resources—petroleum, timber, fisheries, and hydropower. The more ambitious UNSO approach, currently being applied to Mexico and Papua New Guinea in collaboration with their governments and the World Bank, aims at developing a system of "satellite" national accounts that explicitly incorporate the links between economic activity and the use of natural and environmental resources.

tary values on all types of environmental resources. But it is desirable to know how much environmental quality is being given up in the name of development, and how much development is being given up in the name of environmental protection. This Report argues that too much environmental quality is now being given up. There is, however, a danger that too much income growth may be given up in the future because of failure to clarify and minimize tradeoffs and to take advantage of policies that are good for both economic development and the environment.

To clarify these tradeoffs at the national level, efforts are under way in a number of countries to amend the national accounts. Such exercises can be valuable for two reasons. First, they can help indicate how growth of GDP may bring with it environmental costs for today's citizens. For example, the costs of pollution to health and productivity should be taken into account in the same way that other measures of welfare need to be considered. Second, it can help give a more realistic measure of the capacity of an economy to produce. To this end, investment has to be adjusted to take account of depreciation of physical and natural capital. But the accumulation of human capital and the benefits of technical change must also be taken into account to provide an overall picture of an economy's productive capacity.

A number of approaches to measuring environmental costs have been tried in different countries (Box 1.3). A recent pilot study of Mexico's national accounts indicates the potential magnitudes of the adjustments required. When an adjustment was made for the depletion of oil, forests, and groundwater, Mexico's net national product was almost 7 percent lower. A further adjustment for the costs of avoiding environmental degradation, particu-

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larly air and water pollution and soil erosion, brought the national product down another 7 percent. These estimates are preliminary and are only intended to illustrate a methodology. Of more value than these aggregate numbers are sectoral calculations. In the livestock sector, for example, adjustments for the costs of soil erosion sharply reduced the sector's net value added. These calculations in themselves give no indication to policymakers as to whether Mexico's use of natural capital has been in the country's best interest, but they can be useful in reminding policymakers of potential tradeoffs and can assist in setting sectoral priorities.

Economic activity and the environment: key links

This Report will argue that the adverse impact of economic growth on environmental degradation can be greatly reduced. Poor management of natural resources is already constraining development in some areas, and the growing scale of economic activity will pose serious challenges for environmental management. But rising incomes combined with sound environmental policies and institutions can form the basis for tackling both environmental and development problems. The key to growing sustainably is not to produce less but to produce differently. In some situations, such as protection of forests or control of emissions, good environmental policies may cause short-term growth to fall, even as welfare may rise. In other cases—for example, improved soil conservation practices or investments in water supply—the effect on output and incomes is likely to be positive. In still other areas the impacts are unclear. What is clear, however, is that failure to address environmental challenges will reduce the capacity for long-term development.

UNDERSTANDING THE PROBLEM. All economic activity involves transforming the natural world. Why does economic activity sometimes lead to excessive environmental degradation? One reason is that many natural resources are shared and the true value of many environmental goods and services is not paid for by those who use them. Some natural resources are shared because there is no mechanism for enforcing property rights, as with frontier land, and others are shared because, as with the atmosphere, property rights are impossible to enforce. Unless an explicit agreement among users emerges, shared resources will be degraded over time, particularly as the scale of population and economic activity increases. In some cases government policies that subsidize environmental degradation can induce more damage than might otherwise occur. In other cases the poor, with few assets on which to draw, may have no choice but to excessively degrade natural resources.

The most pressing environmental problems are associated with resources that are regenerative but are undervalued and are therefore in danger of exhaustion. Air and water are renewable resources, but they have a finite capacity to assimilate emissions and wastes. If pollution exceeds this capacity, ecosystems can deteriorate rapidly. When fisheries or forests are excessively depleted to meet human needs, critical thresholds may be passed, resulting in the loss of ecosystems and species. Shortages of nonrenewable resources, such as metals, minerals, and energy, the possible exhaustion of which preoccupied early environmental debate, are of less concern. The evidence suggests that when the true value of such nonrenewable resources is reflected in the marketplace, there is no sign of excessive scarcity (Box 1.4).

Water provides an example of an undervalued renewable resource that is showing signs of shortage. By the end of the 1990s six East African countries and all the North African countries will have annual renewable water supplies below the level at which societies generally experience water shortage. In China fifty cities face acute water shortages as groundwater levels drop 1 to 2 meters a year. In Mexico City groundwater is being pumped at rates 40 percent faster than natural recharge. These shortages emerge when water is lost or wasted because its true scarcity value is not recognized. In such cities as Cairo, Jakarta, Lima, Manila, and Mexico City more than half of urban water supplies cannot be accounted for. In many countries scarce water is used for low-value agricultural crops, and farmers pay nothing for the water they use. The misuse of water in the Aral Sea in Central Asia is an extreme example of failure to recognize the value of a natural resource (Box 1.5).

Assessment of whether the regenerative capacity of a natural resource has been exceeded is complicated by uncertainty about the effect of economic activity on the environment. In the cases of soil erosion, atmospheric pollution, and loss of biodiversity, there is often substantial scientific uncertainty about the extent of environmental degradation. Controversy also surrounds the consequences of degradation. What are the health

Box 1.4 The dismal science—economics and scarcity of natural resources

The debate about whether the world is running out of nonrenewable resources is as old as economics. The writings of Malthus and Ricardo, which predicted rapidly growing populations and increasing scarcity of resources, earned economics the name "the dismal science." For natural resources that are nonrenewable, increases in consumption necessarily imply a reduction in the available stock. The evidence, however, gives no support to the hypothesis that marketed nonrenewable resources such as metals, minerals, and energy are becoming scarcer in an economic sense. This is because potential or actual shortages are reflected in rising market prices, which in turn have induced new discoveries, improvements in efficiency, possibilities for substitution, and technological innovations.

The rise in the prices of energy and metals in the 1970s encouraged efficiency gains and substitutions that ultimately reduced the growth of demand. Examples of such technological changes include fiber optics, which replaced copper in telecommunications, the use of thinner coatings of tin, nickel, and zinc in a number of industries, the development of synthetic substitutes, and the recycling of aluminum and other materials. Similar efficiency gains were achieved in the energy sector. The use of metals and of energy per unit of output has declined steadily in industrial countries, although it is generally rising in developing countries. Current consumption as a proportion of reserves has declined for several mineral and energy resources (Box table 1.4). Declining price trends also indicate that many nonrenewables have become more, rather than less, abundant (Box figure 1.4).

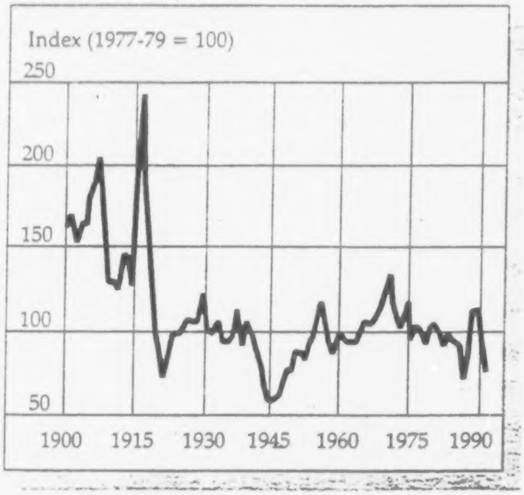
Box table 1.4 Energy and mineral reserves and consumption, 1970 and 1988

	Index of commercial reserves, 1988 (1970 = 100)	*Annual consumption as a percentage of reserves*	
		1970	*1988*
Energy resources			
Crude oil	163	2.7	2.2
Gas	265	2.1	1.5
Mineral resources			
Bauxite	373	0.2	0.1
Copper	131	2.6	3.1
Iron ore	74	0.5	0.8
Lead	75	4.7	8.1
Nickel	72	0.8	1.7
Tin	150	5.4	3.7
Zinc	176	0.3	0.2

Source: World Bank data.

The world is not running out of marketed nonrenewable energy and raw materials, but the unmarketed side effects associated with their extraction and consumption have become serious concerns. In the case of fossil fuels, the real issue is not a potential shortage but the environmental effects associated with their use, particularly local air pollution and carbon dioxide emissions. Similarly, the problems with minerals extraction are pollution and destruction of natural habitat. Because 95 percent of the total material removed from the earth is waste that often contain heavy metals such as copper, iron, tin, and mercury, these commonly find their way into rivers, groundwater, and soils.

Box figure 1.4 Long-run prices for nonferrous metals, 1900-91



Note: The index is based on the real prices of aluminum, copper, lead, tin, and zinc, weighted by the value of developing country exports in 1979-81.
Source: World Bank data.

effects of certain pollutants? What will climate change do to the ecosystem? Can tropical forests be regenerated? The solutions are likewise often unclear. How quickly can the atmosphere restore itself? When will certain cleaner technologies become available and cost-effective? Uncertainty is an inherent part of environmental problems. To reduce it, decisionmakers need better information about environmental processes and social preferences.

Box 1.5 The Aral Sea: lessons from an ecological disaster

The Aral Sea is dying. Because of the huge diversions of water that have taken place during the past thirty years, particularly for irrigation, the volume of the sea has been reduced by two-thirds. The sea's surface has been sharply diminished, the water in the sea and in surrounding aquifers has become increasingly saline, and the water supplies and health of almost 50 million people in the Aral Sea basin are threatened. Vast areas of salty flatlands have been exposed as the sea has receded, and salt from these areas is being blown across the plains onto neighboring cropland and pastures, causing ecological damage. The frost-free period in the delta of the Amu Darya River, which feeds the Aral Sea, has fallen to less than 180 days—below the minimum required for growing cotton, the region's main cash crop. The changes in the sea have effectively killed a substantial fishing industry, and the variety of fauna in the region has declined drastically. If current trends continued unchecked, the sea would eventually shrink to a saline lake one-sixth of its 1960 size.

This ecological disaster is the consequence of excessive abstraction of water for irrigation purposes from the Amu Darya and Syr Darya rivers, which feed the Aral Sea. Total river runoff into the sea fell from an average 55 cubic kilometers a year in the 1950s to zero in the early 1980s. The irrigation schemes have been a mixed blessing for the populations of the Central Asian republics—Kazakhstan, Kyrghyzstan, Tajikistan, Turkmenistan, and Uzbekistan—which they serve. The diversion of water has provided livelihoods for the region's farmers, but at considerable environmental cost. Soils have been poisoned with salt, overwatering has turned pastureland into bogs, water supplies have become polluted by pesticide and fertilizer residues, and the deteriorating quality of drinking water and sanitation is taking a heavy toll on human health. While it is easy to see how the problem of the Aral Sea might have been avoided, solutions are difficult. A combination of better technical management and appropriate incentives is clearly essential: charging for water or allocating it to the most valuable uses could prompt shifts in cropping patterns and make more water available to industry and households.

But the changes needed are vast, and there is little room for maneuver. The Central Asian republics (excluding Kazakhstan) are poor: their incomes are 65 percent of the average in the former U.S.S.R. In the past, transfers from the central government exceeded 20 percent of national income in Kyrghyzstan and Tajikistan and 12 percent in Uzbekistan. These transfers are no longer available. The regional population of 35 million is growing rapidly, at 2.7 percent a year, and infant mortality is high. The states have become dependent on a specialized but unsustainable pattern of agriculture. Irrigated production of cotton, grapes, fruit, and vegetables accounts for the bulk of export earnings. Any rapid reduction in the use of irrigation water will reduce living standards still further unless these economies receive assistance to help them diversify away from irrigated agriculture. Meanwhile, salinization and dust storms erode the existing land under irrigation. This is one of the starkest examples of the need to combine development with sound environmental policy.

EFFICIENCY, TECHNOLOGY, AND SUBSTITUTION. The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes, and environmental investments. According to this view, as populations and incomes rise, a growing economy will require more inputs (thus depleting the earth's "sources") and will produce more emissions and wastes (overburdening the earth's "sinks"). As the scale of economic activity increases, the earth's "carrying capacity" will be exceeded. In reality, of course, the relationships between inputs and outputs and the overall effects of economic activity on the environment are continually changing. Figure 1.4 illustrates that the scale of the economy is only one of the factors that will determine environmental quality. The key question is whether the factors that tend to reduce environmental damage per unit of activity can more than compensate for any negative consequences of the overall growth in scale. Factors that can play a particularly important role are:

- *Structure:* the goods and services produced in the economy
- *Efficiency:* inputs used per unit of output in the economy
- *Substitution:* the ability to substitute away from resources that are becoming scarce
- *Clean technologies and management practices:* the ability to reduce environmental damage per unit of input or output.

Economic policies, environmental policies, and environmental investments all have a role in ensuring that individual behavior takes account of the true value of environmental resources. Economic policies affect the scale, composition, and efficiency of production, which can result in posi-

Box 1.6 Delinking growth and pollution: lessons from industrial countries

Industrial countries have achieved substantial improvements in environmental quality along with continued economic growth. A recent report by the OECD described some of the achievements since 1970. Access to clean water, adequate sanitation, and municipal waste disposal is now virtually universal. Air quality in OECD countries is vastly improved; particulate emissions have declined by 60 percent and sulfur oxides by 38 percent. Lead emissions have fallen by 85 percent in North America and by 50 percent in most European cities. Japan, which has spent substantial amounts on pollution abatement, has achieved the largest improvement in air quality. Emissions of sulfur oxides, particulates, and nitrogen oxides as a share of GDP in Japan are less than one-quarter of OECD averages. Persistent pollutants such as DDT, polychlorinated biphenyls (PCBs), and mercury compounds have also been reduced in OECD countries, as has the frequency of large shipping accidents and oil spills. Forested areas and protected lands and habitats have increased in almost all countries. These improvements have been achieved as a result of annual expenditures on antipollution policies equivalent to 0.8–1.5 percent of GDP since the 1970s. About half of these expenditures were incurred by the public sector and half by the private sector.

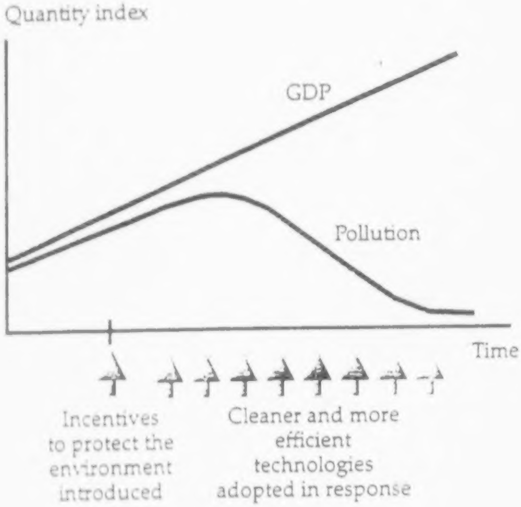
These improvements in environmental quality are even more remarkable when it is recalled that the economies of the OECD grew by about 80 percent over the same period. In many cases economic growth is being "delinked" from pollution as environmentally nondamaging practices are incorporated into the capital stock (Box figure 1.6).

The OECD report, however, also identified a large "unfinished agenda" of environmental problems, as well as emerging issues, that remain to be addressed. Nitrogen oxides, which are emitted largely by transport sources, have increased by 12 percent since 1970 in the OECD countries (except Japan), reflecting the failure of policies and technology to keep up with increases in transport. Municipal wastes grew by 26 percent between 1975 and 1990 and carbon dioxide emissions by 15 percent over the past decade. Human exposure to toxic pollutants, such as cadmium, benzene, radon, and asbestos, remains a concern. Groundwater is increasingly polluted as a result of salinization, fertilizer and pesticide runoff, and contamination from urban and industrial areas. Soil degradation persists in some areas, and encroachment on coastal regions, wetlands, and other natural habitats is still a concern. A number of plant and animal species are endangered; even larger numbers are threatened.

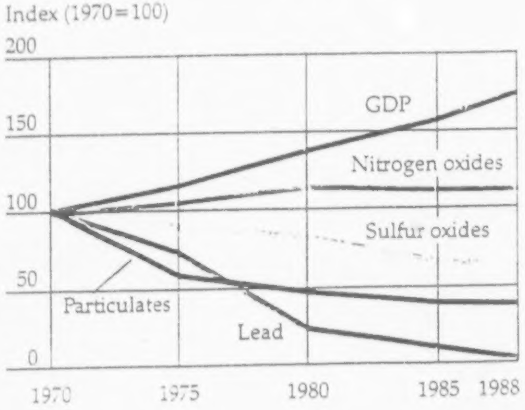
What does the OECD's experience imply for the environmental agendas of developing countries? First, there are many policy lessons—such as the fact that it is often cheaper to prevent environmental degradation than to attempt to "cure" it later. The costly cleanup of hazardous waste sites in several OECD countries gives an indication of what environmental neglect might mean for other countries in the future. Second, many of the environmentally nondamaging technologies and practices developed in OECD countries can be adapted to the needs of developing countries. Cleaner technologies and practices can be acquired through trade and foreign direct investment, as well as through international cooperation. Third, to the extent that environmental degradation in the OECD countries affects developing countries, as in the case of climate change and ozone depletion, polluters should pay and victims should be compensated.

Box figure 1.6 Breaking the link between growth in GDP and pollution

The theory


Quantity index
GDP
Pollution
Time
Incentives to protect the environment introduced
Cleaner and more efficient technologies adopted in response

The practice: GDP and emissions in OECD countries



Note: GDP, emissions of nitrogen oxides, and emissions of sulfur oxides are OECD averages. Emissions of particulates are estimated from the average for Germany, Italy, Netherlands, United Kingdom, and United States. Lead emissions are for United States.
Sources: OECD 1991; U.S. Environmental Protection Agency 1991.

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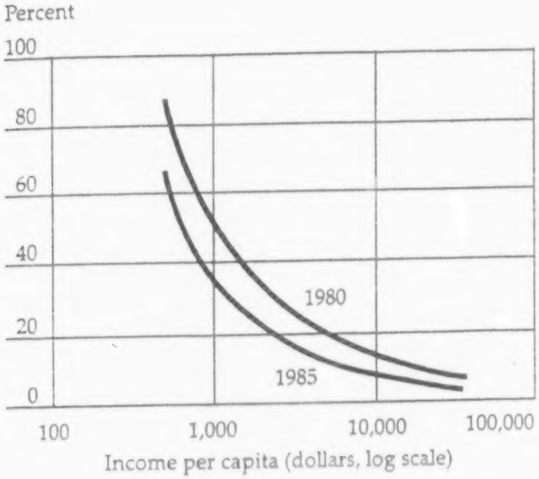
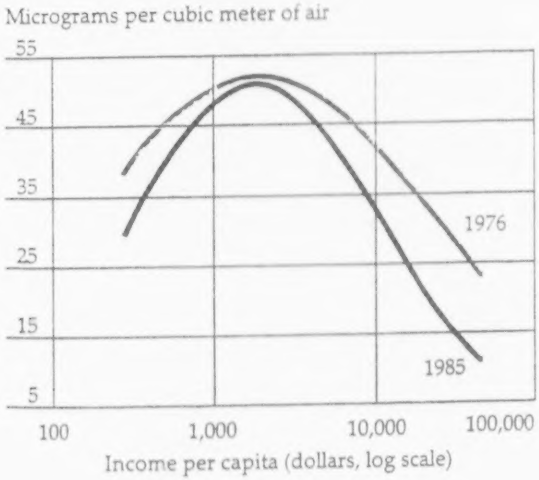
Figure 1.5 Changes in urban sanitation and sulfur dioxide concentrations over time at different country income levels

Urban population without adequate sanitation



Concentrations of sulfur dioxide



Sources: Shafik and Bandyopadhyay, background paper; World Bank data.

tal quality improves as income rises. This is because increased income allows societies to provide public goods such as sanitation services and because once individuals no longer have to worry about day-to-day survival, they can afford profitable investments in conservation.

Some problems are observed to get worse as incomes rise. Carbon dioxide emissions and municipal wastes are indicators of environmental stress that appear to keep rising with income. But this is because no incentives yet exist to change behavior. The costs of abatement in these cases are relatively high, and the benefits of changing behavior are perceived to be low—partly because (in the case of carbon dioxide) they would accrue mainly to other countries. When societies have decided to enforce a change in behavior—through regulations, charges, or other means—environmental quality has improved. Progress in reducing water pollution and emissions of particulates, lead, and sulfur dioxide are examples of how higher-income countries have been able to break the link between growth and environmental degradation. This is not easy—it requires strong institutions and effective policies—but it can be done. It explains why so many environmental indicators show an initial deterioration followed by an improvement. As incomes grow, the ability and the willingness to invest in a better environment rise.

Past patterns of environmental degradation are not inevitable. Individual countries can choose policies that lead to much better (or worse) environmental conditions than those in other countries at similar income levels. In addition, technological change, coupled with improved understanding of the links between economic activity and environmental damage, is enabling countries to grow more rapidly with less environmental impact than was possible earlier. Figure 1.5 illustrates this for a cross-section of countries. At any given income level, a higher proportion of people in any country is likely to have access to sanitation today than in the past. The same can be true of progress in reducing air pollution. Concentrations of sulfur dioxide are lower today than in the past, so that someone living in a country with a per capita income level of $500 is more likely to breathe cleaner air than in previous decades. The adoption of environmental policies and the investment and technological innovations induced by such policies imply that the environmental mistakes of the past do not have to be repeated.

The nature of the challenge

During the working lifetime of children born today, the population of the world will almost double. By the middle of the next century almost one-third of the world's population will live in countries with a population density of more than 400 per square kilometer—equivalent to the density of the Netherlands or the Republic of Korea today. The next generation will also see the size of the world economy triple. Under simple extrapolation of current practices, this growth would lead to severe environmental degradation. Yet in virtually every economic sector, environmentally less damaging practices are available and are in use in a number of countries. For almost every challenge—in water supply and sanitation, or energy and industrial output, or food production—there are possibilities for growing more sustainably.

The challenge for water supply and sanitation will be to respond to the backlog of demand while meeting the needs of growing populations. Making clean water available to everyone in the next generation will require that service be extended to an additional 3.7 billion people living in urban areas and about 1.2 billion rural inhabitants. Since only about 1.5 billion urban residents currently have access to clean water, the magnitude of the task is apparent. For sanitation the problem is even larger; the number of urban dwellers currently served is little more than 1 billion. For a country like Nigeria, providing access to clean water for the entire population by 2030 will imply increasing the number of urban connections by four times and the number of rural connections by almost nine times. To prevent the number of people without access to adequate sanitation from rising, the population covered will have to increase to 6.5 times the current number. Policies to meet these challenges are discussed in Chapter 5.

The challenge for energy and industry will be to meet the projected growth in demand while controlling pollution. Total manufacturing output in developing countries will increase to about six times current levels by 2030. Average emissions of air pollutants per unit of electric power generated would have to be reduced by 90 percent to avoid an increase in total emissions from this activity. Emissions from heavily polluting industries—chemicals, metallurgy, paper, and building materials—will also require large reductions in discharges of air and water pollutants and in wastes produced if a worsening of industrial pollution is to be prevented. In the Philippines, for example, manufacturing output is likely to grow to nine or ten times the current level, and demand for electric power will rise even more rapidly. This means that many industries will have to reduce emissions per unit of output by between 90 and 95 percent to avoid worsening pollution.

The technologies for achieving such reductions in pollution from energy and industry already exist in most instances. Many possibilities also exist for dramatic improvements in pollution prevention—switching to cleaner-burning fuels or recycling industrial wastewater, for example. Cleaner processes often yield productivity gains and cost reductions as well because they use materials more frugally. The scope for pollution abatement and prevention in industry and energy, and the policies for inducing these new technologies, are discussed in Chapter 6.

The challenge for agriculture will be to meet developing countries' expected demand for food. Total world consumption of cereals will have to almost double by 2030. To protect fragile soils and natural habitats, almost all of this increase will have to be achieved by raising yields on existing cropland rather than by extending the area under cultivation. There is little doubt that cultivated soils have the capacity to meet future increases in world agricultural demand so long as they are well managed. But intensification of production will involve the application of much higher levels of fertilizers and pesticides, as well as significant improvements in the allocation of water for agricultural use. Doubling food production in India by 2030 can be achieved by maintaining past rates of crop yields but will require a fourfold increase in fertilizer application. By 2030 average yields in India would have to reach the level of those in China today.

Such gains in food production increase the risk of soil degradation, misuse of pesticides, spillovers from chemical applications, and excessive drawdown of water. Techniques such as integrated pest management, minimum tillage, agroforestry, integrated crop and livestock management, and soil-enriching crop rotations will be needed to reduce land degradation and increase yields. This will often require better-educated farmers, and sometimes social changes as well. When governments are committed to allocating resources to research and extension services and to providing undistorted incentives, many farmers are quick to adopt these less-damaging practices. Policies for improving the management of natural resources, especially of agricultural land, will be discussed in Chapter 7.

Policies and institutions

Without technologies and practices that can be applied at reasonable cost, environmental improvement is difficult. But without the backing of appropriate policies, even the most environmentally

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helpful technologies and practices will not necessarily be applied, unless (as is often the case in industry) they are more productive than existing methods. The principles of sound environmental policy (described in Chapter 3) are well understood. But they are difficult for national governments to introduce and are even more difficult to translate into international agreements. National governments may be reluctant to challenge those who cause environmental damage; they are likely to be the rich and influential, while those who suffer most are often the poor and powerless. The institutional obstacles to sustainable development are discussed in Chapter 4.

If institutional obstacles to addressing national environmental problems are large, they are even greater for international problems such as greenhouse warming and the preservation of biodiversity. It may be difficult to reach agreement among many different countries, each of which may perceive its national interest differently. If countries do not think that the benefits of agreement are worth more to them than the costs of refusing to cooperate, they may be willing to join only if other countries are willing to compensate them for doing so. The complications of addressing global environmental problems are analyzed in Chapter 8.

A strategy for sustaining development

The challenges facing this generation are formidable. Many countries have not yet achieved acceptable living standards for their people. Economic growth that improves human welfare is urgently needed. Protecting the environment will be an important part of improving the well-being of people today, as well as the well-being of their children and grandchildren. This Report suggests a threefold strategy for meeting the challenge of sustainable development.

- *Build on the positive links.* Policies for growth promote efficient use of resources, technology transfer, and better-working markets—all of which can help in finding solutions to environmental challenges. Rising incomes can pay for investments in environmental improvement. Policies that are effective in reducing poverty will help reduce population growth and will provide the resources and knowledge to enable the poor to take a longer-term view.
- *Break the negative links.* Rising incomes and technological advances make sustainable development possible, but they do not guarantee it. Usually, additional incentives that capture the true value of the environment will be required to induce less-damaging behavior. Effective environmental policies and institutions are essential.
- *Clarify and manage the uncertain links.* Many relationships between human activity and the environment remain poorly understood, and there will always be surprises. The response should be investment in information and research and the adoption of precautionary measures, such as safe minimum standards, where uncertainties are great and there is a potential for irreversible damage or high costs in the long run.